# TIRES AS A FUEL SUPPLEMENT: FEASIBILITY STUDY

Report to the Legislature
January 1992

CALIFORNIA INTEGRATED WASTE MANAGEMENT BOARD

# State of California

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We would like to express our appreciation for the cooperation received from numerous industry representatives in gathering the information necessary to complete this study.

# Preface

This report is on the feasibility of using waste tires as a fuel supplement for cement kilns, lumber operations, and other industrial processes. It has been written in consultation with the California Air Resources Board (CARB) and the California Energy Resources Conservation and Development Commission (CEC) to fulfill the reporting requirement of Assembly Bill 1843 of 1989 (Chapter 35, Statutes of 1990, now codified as Public Resources Code §42800 *et seq.*).

## Disclaimer

The statements and conclusions of this report are those of the California Integrated Waste Management Board. The report was made available for public review and comment (at a workshop held on December 18, 1991) before adoption by either the California Integrated Waste Management Board or the State of California. The State makes no warranty, express or implied, and assumes no liability for the information contained in the succeeding text. Any mention of commercial products or processes shall not be construed as an endorsement of such products or processes.

# Table of Contents

# Glossary of Terms

**Asphalt Concrete** A highway paving material consisting of a mixture of asphalt binders and solid aggregate particles.

**Asphalt-Rubber** A blend of asphalt cement, reclaimed [not devulcanized] tire rubber, and certain additives in which the rubber component is at least 15 percent by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles. (ASTM D8-88).

**Buffings** Fine rubber particles which are ground from tire casings. Either a by-product of the retreading industry or ground for the buffings only.

**Chipped Tires** Pieces of rubber usually one inch by one inch (1x1) or two inches by two inches (2x2).

**Chopped Tires** Tires cut into usually four or more large pieces.

**Criteria Air Pollutant** Air pollutants for which national ambient air quality standards have been established. These are ozone, carbon monoxide, sulfur dioxide, nitrogen oxides, particulate matter, and lead. They do not include Toxic Air Contaminants.

**Crumb Rubber** Particles of rubber from about one-eighth inch to about one-half inch in size.

**Cryogenic Processing** The technology of using liquid nitrogen to freeze tire rubber to a brittle state and hammering it into granulate.

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| Cyclone | A pollution control device used to reduce the amount of particulate matter exhausted to the atmosphere by using conical shaped ducts to separate most of the larger particles. |
| Devulcanization | A chemical process used to return rubber to its crude, unhardened form to be reused. |
| Granulated Tire Rubber | Fine rubber particles similar to buffings; often produced using cryogenic processing technology. |
| Heavy-Duty Tire | Tires used on trucks and buses typically weighing between 80 and 140 pounds. |
| Hogged-Fuel | Chipped wood waste generated from lumber operations, pulp manufacturing, and other chipping operations which contains substantial moisture content. |
| Light-Duty Tire | Tires used on passenger-vehicles and light-duty trucks typically weighing between 12 and 30 pounds. |
| Multiclone | Two or more cyclones arranged in a series. |
| Reclaimed Rubber | Rubber which has been devulcanized for reuse as a raw material. |
| Rubber-Modified Asphalt Concrete | Any asphalt concrete which contains tire rubber as a partial substitute for aggregate. |

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| **Shredded Tires** | Strips of rubber from about one inch wide to about six inches wide, varying in length. Also known as "single-pass" shredded tires. |
| **Supplemental Fuel** | A combustible material which displaces a small portion (typically less than 25 percent) of traditional fossil fuel usage. |
| **Tire-Derived-Fuel** | A uniformly shredded product produced from whole scrap tires for use as a fuel. |
| **Toxic Air Contaminant** | An air pollutant (other than criteria air pollutants) which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health (Health and Safety Code Section 39655). |
| **Used Tire** | A pneumatic tire that has been removed from the wheel of a vehicle, including tires that may be reused as a vehicle tire, or retreaded. |
| **Waste Tire** | A pneumatic tire that is no longer suitable for its original intended use or for repair due to wear, damage, or defect. |

# Acronyms

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| AR | Asphalt-Rubber |
| BTU | British Thermal Unit |
| CalTrans | California Department of Transportation |
| CARB or ARB | California Air Resources Board |
| CEC | California Energy Resources Conservation and Development Commission |
| CEQA | California Environmental Quality Act |
| CFB | Circulating Fluidized Bed Combustor |
| CIWMB | California Integrated Waste Management Board |
| CO | Carbon Monoxide |
| CPCA | Canadian Portland Cement Association |
| DHS | California Department of Health Services |
| EIR | Environmental Impact Report |
| EPA | Environmental Protection Agency (federal) |
| EPRI | Electric Power Research Institute |
| ESP | Electrostatic Precipitator |
| FHWA | Federal Highway Administration |
| HCl | Hydrogen Chloride |
| MSW | Municipal Solid Waste |
| MW | Megawatt |
| NOx | Nitrogen Oxides |
| NTDRA | National Tire Dealers and Retreaders Association |
| PAH | Polyaromatic Hydrocarbon |
| PCB | Polychlorinated Biphenyls |
| PM | Particulate Matter |
| RDF | Refuse-Derived-Fuel |
| RUMAC | Rubber-Modified Asphalt Concrete |
| RMA | Rubber Manufacturers Association |
| SOx | Sulfur Oxides |
| TDF | Tire-Derived-Fuel |
| TRIB | Tire Retread Information Bureau |

# Executive Summary

## Synopsis

This report has been prepared to fulfill the reporting requirements of Assembly Bill 1843 (Chapter 35, Statutes of 1990, now codified as Public Resources Code §42800 *et. seq.*). The California Integrated Waste Management Board (CIWMB or Board) is required to report to the Legislature on the feasibility of using tires as a fuel supplement for cement kilns, lumber operations (including pulp and paper manufacturing), and other industrial processes (Public Resources Code §42850).

To adequately assess the feasibility of using tires as a fuel, other uses of waste tires were also examined. The report explores the technical, environmental, economic, geographical, regulatory, and institutional factors which may affect these uses.

Over 27 million used tires are generated each year in California of which 21 million are waste tires (see Figures 1-2 and 1-3). While tires constitute only about one-half of one percent by weight of the total municipal solid waste stream, their size, shape, and physical and chemical properties present an unusually challenging disposal problem.

In the past few years, landfill operators have raised the fees for accepting whole tires (or refused to accept them at all) resulting in the creation of numerous stockpiles. When improperly managed, stockpiles present significant risks to the environment and public health. The risks arise from the potential for fires in tire piles and the harboring of disease vectors such as mosquitoes.

Whole tires are expensive to bury in conventional landfills because, when whole, 50 to 75 percent of the space they occupy is void. Shredding reduces the volume and eliminates other problems associated with landfilling and storage; however, tire shredding equipment is expensive to purchase and operate and consumes a great deal of energy. While shredding and monofilling tires is a method to safely store this valuable resource, the large amount of tires available makes it doubtful that buried material would ever be economically recovered.

In terms of value as a fuel, tires are equivalent to coal and, as such, constitute an excellent energy resource. The Board has concluded that, under the right conditions, tires can be safely burned as a fuel supplement. Use of tires in cement kilns displaces coal. That means the coal does not have to be mined or transported and, if the emissions are equivalent, an overall environmental benefit is realized because the tires are consumed in a manner that leaves no residue. Emissions tests at two California cement kilns burning waste tires with coal fuel showed no appreciable difference in toxic air contaminant emissions when compared to burning coal fuel only. The use of tires by cement kilns is a method with existing technology that could be quickly implemented, and has the potential to eliminate all of the waste tires stockpiled and generated.

The economic savings from the use of tire fuel by the cement industry will result in the payback of capital investments ($500,000 to $1,000,000) within about one year. As alternative uses develop and market forces dictate, the cement industry may easily reduce or eliminate the use of tires as a fuel supplement with little impact to their operations.

The Board recommends that support be provided for the use of tires as fuel in cement kilns. To address concerns on the variability in emissions, funding for further source testing should be provided as well as assistance with air quality permitting. Other long-term methods of recycling tires must also be developed to provide diversity and avoid dependence on only one option.

The Board also recommends that support be continued for the use of Rubber-Modified Asphalt Concrete (RUMAC) and Asphalt-Rubber (AR) through additional funding of research by CalTrans, encouraging the use in maintenance applications, and establishment of processing specifications.

Other options for waste-tire use should be evaluated by considering factors such as the quantity of tires diverted, the costs of the option, the markets for the product, and the degree to which the option mitigates or avoids adverse environmental effects. Supporting a variety of options will aid the natural evolution of the most valuable uses and allow the marketplace to determine the flow of waste tires.

## Background

Before World War II, tires were made from natural rubber and were commonly retreaded several times. Currently, tires are manufactured primarily from relatively plentiful and inexpensive petroleum-based chemicals. In contrast to years past, today there is a lack of existing recycling and resource recovery options for the large quantity of tires disposed. Waste tires constitute only about one-half of one percent by weight of the total municipal solid waste generated in California; however, due to their size, shape, and physical and chemical properties, they present an unusually challenging disposal problem.

Whole tires are expensive to bury in conventional landfills because they occupy volumes greater than their weight fraction would indicate. When whole tires are disposed of in bulk, 50 to 75 percent of the space they occupy is void. Shredding reduces the volume and eliminates other problems associated with landfilling and storage; however, the processing equipment is expensive to purchase and operate.

A common problem at landfills is that whole tires tend to rise or "float" to the surface of a landfill due to their buoyancy compared to the surrounding wastes and soil. As a result, tires may penetrate the final cover following the closure of the landfill.

As landfill operators have raised the fees for accepting whole tires (or refused to accept them at all), numerous large stockpiles have developed. Improperly managed stockpiles present significant risks to the environment and public health. The risks arise from the potential for fires in tire piles and the harboring of disease vectors such as mosquitoes.

Tires are highly combustible, and when stockpiled whole, an almost unlimited supply of oxygen is available for combustion. Tire fires, most often started by arson, generate a large amount of heat and are extremely difficult to extinguish because virtually every tire in the pile has access to air. Some tire fires have continued for months. Open, uncontrolled combustion of tire piles generates smoke (carbonaceous particulates) and toxic air pollutants, including benzene and polynuclear aromatic hydrocarbons. The intense heat leads to generation of a pyrolytic oil that becomes mixed with the water used to fight the fire. The oil may then contaminate surrounding soils, surface waters, and ground water.

Whole tires can collect and retain water, and as a result, may become a haven and breeding ground for mosquitoes, rodents, and other carriers of disease.

### Tire Characteristics

Tire manufacturers use many different rubber compounding formulas for various applications, but they all include natural and synthetic rubbers, carbon black, sulfur, zinc oxide, and various extenders and anti-oxidants. Generally, 25 to 30 percent of the rubber used for modern radial tires is natural rubber, with the balance being synthetic rubbers.

The physical characteristics of tires make them difficult to store and transport. Tires are not easily compressed or packed together and require large volumes of space when stored or transported in whole form. A solution to this problem is to shred or chip whole tires to reduce their volume, but that consumes a great deal of energy and requires powerful machinery to overcome the strength and resiliency of the rubber and steel. While shredding and monofilling tires is a method to safely store this valuable resource, the large amount of tires available makes it doubtful that buried material would ever be economically recovered (in part due to contamination).

In terms of value as a fuel, waste tires are an excellent energy resource. Tire rubber has a heating value of 12,000 to 16,000 British Thermal Units per pound (BTU/lb), depending on the composition and whether or not the steel has been removed. For comparison, bituminous coal has values ranging between 11,000 and 13,000 BTU/lb. With an energy content of approximately 250,000 BTU, a single 18 pound waste tire contains the energy equivalent to about two gallons of gasoline. Refer to Table 1-1 for a comparison of heating values for various fuels.

## Alternative Uses

In recent years, waste management professionals have developed a hierarchy of preferred techniques for dealing with wastes. This hierarchy ranks source reduction as the first method for managing wastes, followed by reuse, recycling, transformation, and, lastly, landfill disposal. The report examines the alternative uses for tires and follows the order set forth in the waste management hierarchy. Figure ES-1 presents a flowchart which illustrates scrap tire management, and as such, represents an outline of the structure of this report.

Source reduction techniques for tires focus on proper care to extend the life of the tire as much as possible. Used tires can be reused or retreaded. Tires that have been damaged or rendered un-roadworthy can be recycled to produce a variety of new products; unfortunately, few of these uses consume the complete tire nor do they have the potential to consume a large number of tires. Many recycling methods use only buffings or crumb rubber and leave the casing or belting as a residue.

Exporting waste tires is an option which could be quickly developed. The main benefits could be use of the tire through the complete life of the tread (below the California legal tread limits) and the elimination of the problem of disposal in California. After export, however, control of the method of disposal is lost, and if the tires are used as fuel (the most likely case), they will probably be used at facilities without adequate pollution controls.

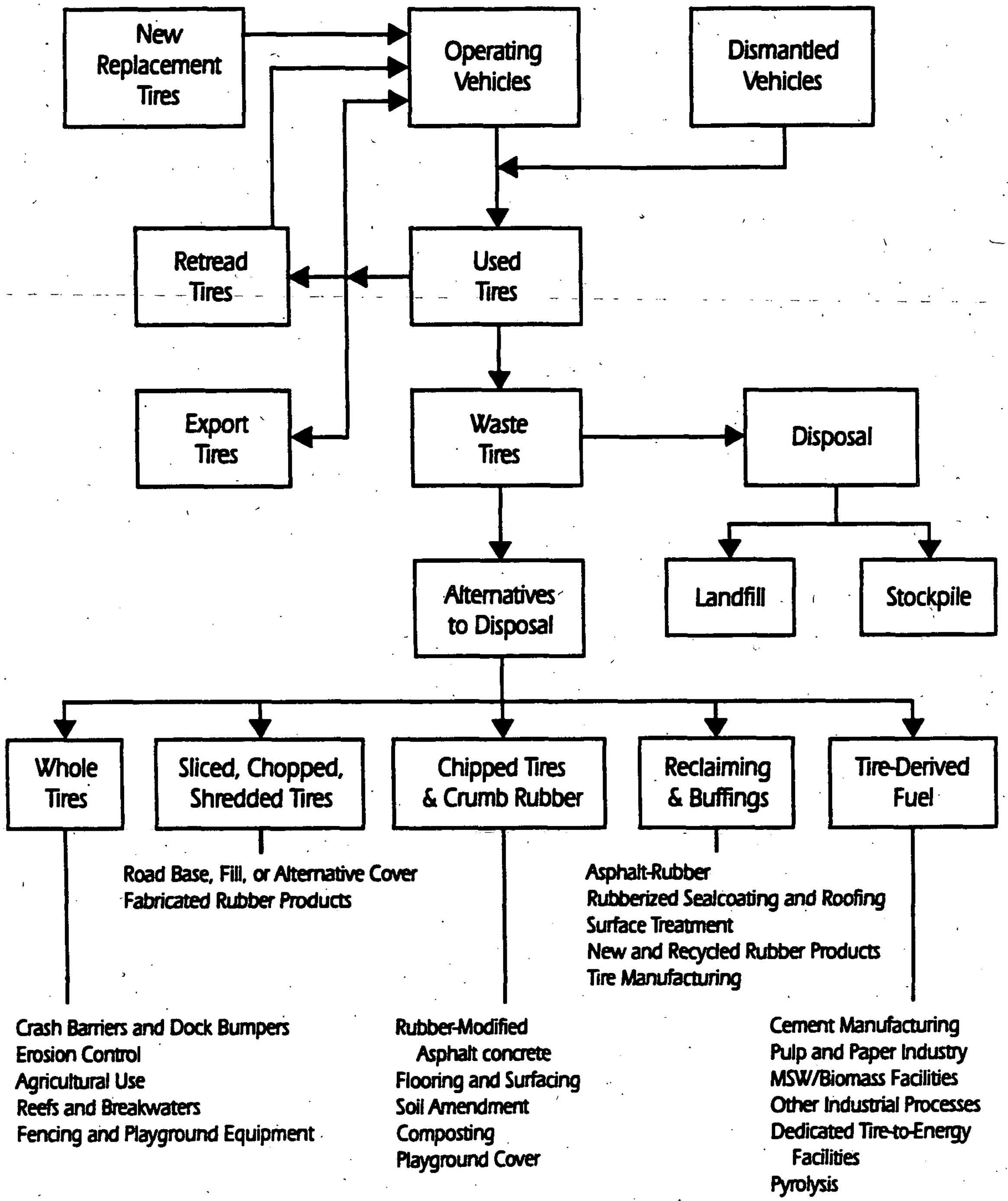
Methods to re-use tires are discussed in Sections 2.1 and 2.2, and products made from recycling tire rubber are discussed in detail in Section 2.3. Many recycling methods are not anticipated to consume large quantities of tires; for example, products such as floor mats or coverings, running tracks, and sealcoatings use crumb rubber only. RUMAC and AR are the major alternatives for recycling tires and are discussed in brief below. This is followed by a discussion of various transformation methods to recover energy through combustion.

### Rubber-Modified Asphalt Concrete and Asphalt-Rubber

A promising alternative for using waste tire rubber, in the form of crumb rubber, is RUMAC, also known as the dry process. (For the purposes of this report, crumb rubber is defined as particles of rubber from one-eighth inch to about one-half inch in size. This definition was selected because of the inconsistency among the many sources of information reviewed during this study.) The two types of RUMAC are Plusride™ and a Generic Process. Both processes incorporate crumb rubber as a partial substitution for aggregate. Crumb rubber is produced by sequentially shredding a whole tire down to a specified size. Approximately 8,000 to 12,000 tires per mile of two-lane, three inch-lift roadway are used in RUMAC. Both processes are more expensive than conventional asphalt due to the additional cost of the tire rubber, the lack of experienced contractors, and the limited use to date; however, RUMAC has been shown to be cost effective in some cases. RUMAC can be laid thinner, have reduced maintenance costs, and have a longer life than

**FIGURE ES - 1**

SCRAP TIRE GENERATION, USE AND DISPOSAL



conventional asphalt concrete (see Sections 2.3 and 3.4 for a discussion of the processes and costs).

Asphalt-Rubber (AR, also known as the wet process) differs from RUMAC in several ways. First, tire buffings or granulated rubber, not crumb rubber, are used. Secondly, unlike RUMAC, AR involves mixing the tire buffings with the liquid asphalt, creating a new binder material. Tire buffings are generated either by retreading operations when the remaining tread is ground off of the tire casing prior to the application of new tread, or when waste tires are ground to produce production buffings. Approximately 1600 tires per mile of two-lane road are used in this process. The expense of the buffings and the need for specialized equipment for blending and storing the binder result in increased paving costs. Potential air pollution concerns also exist because melting tire rubber may release volatile organic compounds (VOC).

### Transformation - Cement Kilns

Cement manufacturing involves grinding and roasting minerals in a rotary kiln to a temperature of about 2700°F to form partially fused nodules which are called clinker. The kiln operation is the most important step in producing cement because the strength and other properties of cement depend on the quality of the clinker. Refer to Figure 2-1 for an illustration of a typical cement kiln process.

Currently, there is one cement company operating in California which supplements its primary fuel (coal) with tires, and two which have performed test burns with TDF. Calaveras Cement Company has been burning TDF at its Redding facility since 1982. Currently TDF accounts for about 20 percent (equivalent to 1.7 million tires per year) of the total fuel consumed.

Southwestern Portland Cement Company (Victorville) has completed air emissions testing as a prerequisite to the local air district's permitting process. RMC Lonestar Cement Company (Davenport) has also completed emissions testing with the use of shredded tires as a fuel supplement. Additional testing is planned at RMC Lonestar to evaluate emissions from whole tires. Combined, these three facilities could consume over six million tires per year (at 20 percent supplemental fuel).

Some capital expenditures are required for tire-fuel feed systems; industry sources indicate these are typically less than $500,000. The fuel savings incurred commonly result in pay back periods of one year or less. In general, under current local air district requirements, upgrading of air pollution control equipment is not necessary for burning tires as a fuel supplement in the cement manufacturing industry. Air emissions issues are discussed in detail in Section 3.3.1.

### Transformation - Pulp and Paper Mills

Historically, pulp mills have been largely self-sufficient in meeting their steam, heat, and electrical energy demands due to the immediate availability of wood wastes generated within the plant by the cutting, debarking, and chipping processes, and from mill wastewater sludges. These are combusted in hogged-fuel or combination-fuel power boilers to produce process steam and to generate electrical energy.

Due to the high moisture content and low heating value associated with typical composite wood wastes, higher heating value fossil fuels such as coal or fuel oil are often required to stabilize operation of combination-fuel boilers. The high heating value and low moisture content of tires make them a suitable fuel to co-burn with wood wastes. Dewired TDF (heating value approximately 15,000 to 16,000 BTU/lb) is usually required to avoid handling problems in existing systems. When shredded or chipped tires are used as a supplemental fuel, they often get caught in the fuel feed system or in the boiler due to exposed steel wire.

### Transformation - Biomass Facilities

There are 60 combustion facilities in California which burn wood wastes, agricultural wastes, or MSW to produce steam and electricity (cogeneration), electricity only, steam only, or hot water. The biomass facilities consume in excess of eight million tons per year of wood waste (including lumber mill and urban wood wastes), agricultural waste, and animal waste. Lumber mill waste is used as fuel more than any other biomass material.

Operational problems for any combustion facility can result if the fuel is incompatible with existing fuel handling and feed system designs. Fuel size, shape, and handling characteristics must be considered. Exposed steel wire in TDF can get caught in these systems. Where problems occur, fuel specifications must be revised (such as switching to dewired TDF), existing fuel handling and feed systems must be altered, or new systems must be designed and installed. The air pollution control equipment on some existing facilities may not be adequate to co-fire TDF; however, it may be possible for biomass facilities equipped with adequate emissions controls to burn a small amount of TDF without significant environmental impacts.

### Tires-to-Energy Facilities

Whole or shredded tires may be directly combusted at dedicated tire-to-energy facilities. Oxford Energy Company designed, built, and has been operating the Modesto Energy Project in Westley, California, since 1987. This facility incinerates about five million whole tires annually to generate about 14 MW of electrical power - enough to supply the electrical needs of 14,000 homes.

## Impediments

Many factors impede the use of waste tires, including energy requirements of transportation and processing; product quality requirements; potential environmental impacts; economics; and siting, regulatory, and permitting requirements.

The energy required to transport, shred, and process waste tires may inhibit the use of tires. Because of volume differences, transportation of whole tires is less efficient than transporting shredded tires. The processing or shredding of tires also requires large amounts of energy because of tire toughness and durability.

The high cost to process or use waste-tire rubber and limited revenues from the sale of products are economic barriers to waste-tire use. These costs could be offset by collection fees and by avoiding the landfill disposal fee.

Due to competition with virgin materials or products not using waste-tire rubber, the use of recycled materials or products using waste-tire rubber may be impeded due to the impression (or actuality) of inferior quality. Rather than compromise product quality or marketability, manufacturers have chosen to use virgin rubber instead of recycled rubber.

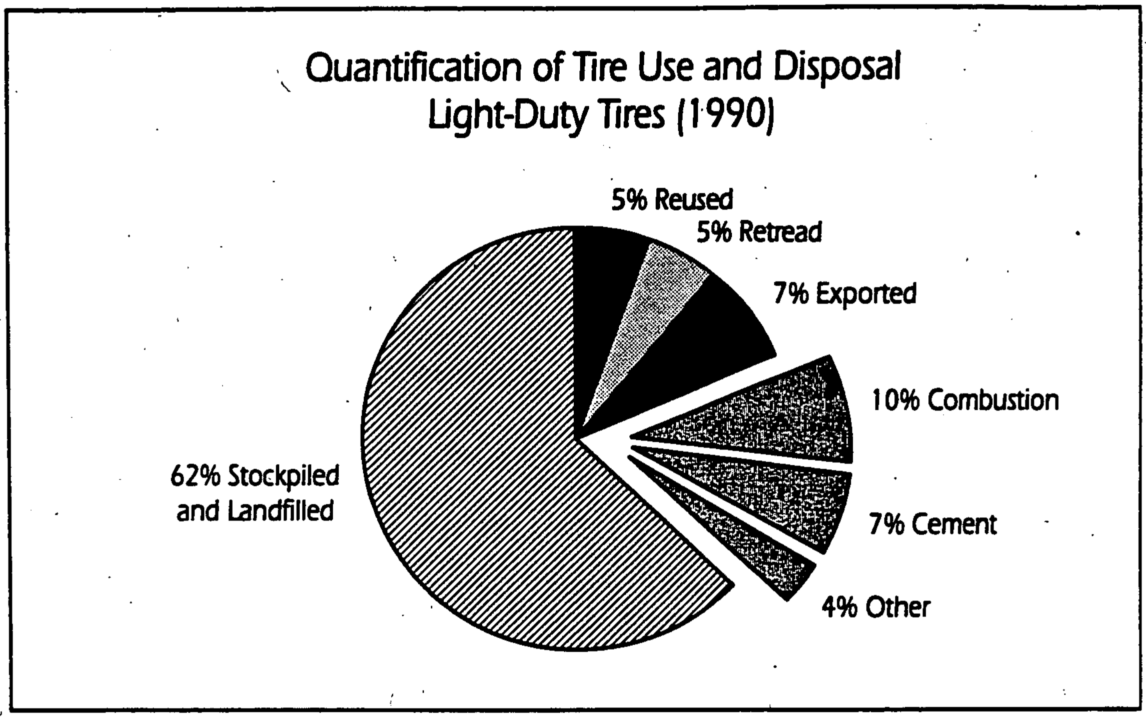
Performance and air pollutant emissions tests will need to be conducted prior to using tires as a fuel supplement at any facility. Results of these tests would be used to determine whether or not TDF is a compatible fuel for these facilities, with consideration for process performance, economics, and environmental impacts.

Alternative uses of waste tires, in general, will be impeded if environmental impacts, including air emissions, water contamination, and wastes and by-products are significant and are not easily handled. Historically, the lack of emissions data has led to delays in siting and permitting facilities using tires.

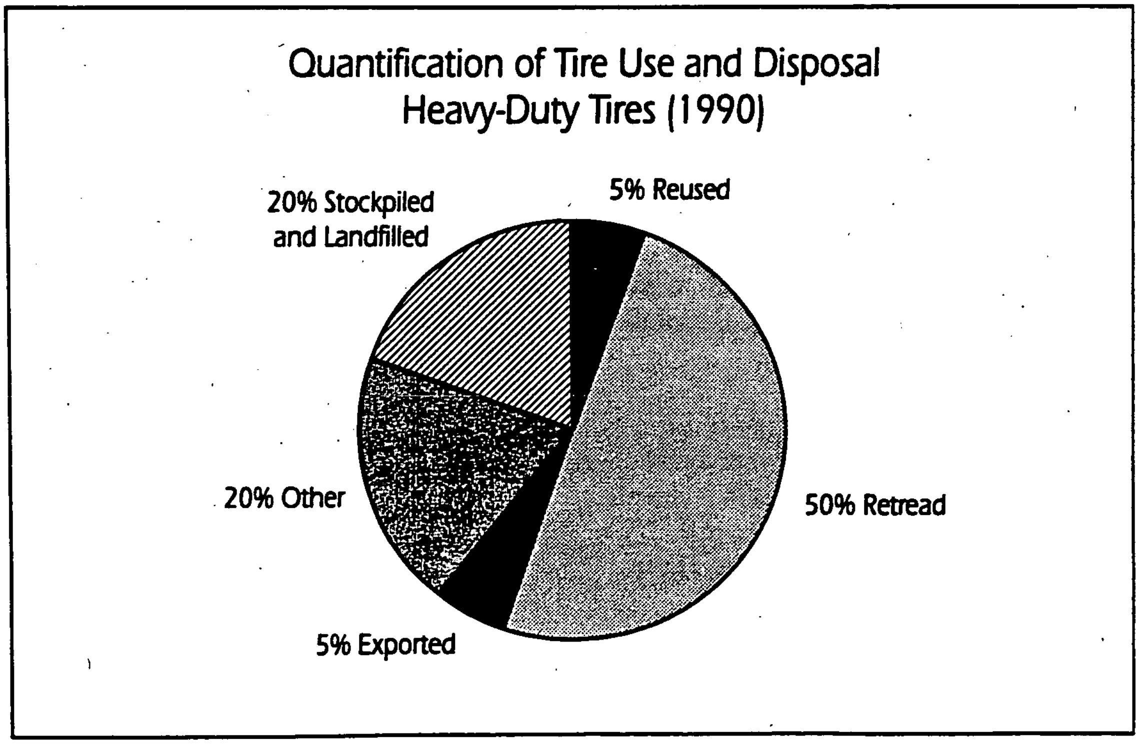
## Consumption of Waste Tires

Figure ES-2 illustrates the recovery and disposal distribution of *used* tires for both light-duty passenger (23.4 million) and heavy-duty truck (3.6 million) tires. Because a large fraction of the used tires (as defined in this study) is recovered for reuse and retreading, it is more correct to compare the consumption potential of industries with the annual *waste* tire generation rate of 20.9 million (19.5 million light-duty and 1.4 million heavy-duty tires).

**FIGURE ES - 2**



Quantification of Tire Use and Disposal
Light-Duty Tires (1990)
5% Reused
5% Retread
7% Exported
10% Combustion
7% Cement
4% Other
62% Stockpiled and Landfilled

Quantification of Tire Use and Disposal
Heavy-Duty Tires (1990)
20% Stockpiled and Landfilled
5% Reused
50% Retread
20% Other
5% Exported

At least another 32 million tires have been identified as stored in stockpiles across the state. The number of stockpiled tires which are of concern may be as low as 20 million, because the largest stockpile in the state is dedicated to the Oxford Energy facility. Tires which have been in stockpiles for some time tend to be contaminated with dirt and rock and can be difficult to process in shredders. Older tires are also of different composition or have been oxidized or otherwise damaged by exposure to the elements. Often the simplest and least costly approach is to combust them whole; therefore, in the discussion of recycling, newly generated waste tires are the principal focus.

RUMAC and AR have the potential to consume a significant number of waste tires if the tires are first reduced to crumb rubber, granulated rubber, or buffings. Because some of these processes leave a large portion of the casing as residue, it will be imperative to simultaneously develop recycling or disposal techniques for the waste (steel-belting, bead wire, sidewalls, etc.).

California cement manufacturing facilities, due to their locations and large energy requirements, could consume all of the waste tires generated in the state using a minimal amount of transportation and processing energy. Of the eleven facilities in California, ten are in or near densely populated areas where large quantities of waste tires are generated (see Figure 4-1). In addition, many existing stockpiles are located near these facilities.

The consumption potential for the cement industry is nearly 25 million tires per year based on the use of 20 percent as supplemental fuel and an equivalent weight of 18 pounds per tire. This exceeds the generation rate of waste tires in California.

Currently only one pulp and paper mill in the state burns hogged-fuel. The pulp and paper industry has a limited potential to consume a significant number of tires.

California biomass combustion facilities also have some potential to consume a significant number of waste tires; however, biomass facilities would have to be evaluated on a case-by-case basis to determine if air pollution control requirements could be met. As discussed in Section 2.4.3, 57 facilities are currently operating in California, eight of which have the potential to use waste-tire rubber as a supplemental fuel. These eight facilities are within 100 miles of a large population center and seven of the eight are located within 40 miles of existing waste-tire stockpiles. These eight facilities could consume about six million waste tires per year if five percent (by weight) of the current fuel was replaced with tire rubber.

## Introduction

Since the first pneumatic tires were introduced nearly one hundred years ago, tire manufacturing has developed into one of America's most competitive industries. The large volume of the tire market has compelled, and will continue to compel, manufacturers to produce ever superior products to meet ever changing requirements. Tire manufacturing today is a delicately balanced technology using specialized raw materials and computerized production methods to create a nearly indestructible tire. The very properties which are instilled into a tire lead to the difficulties inherent with its disposal.

During World War II, scrap tire management was a relatively minor problem since rubber was scarce and tires were expensive. At that time tires were made from natural rubber and were commonly retreaded several times. Currently, tires are manufactured primarily from relatively plentiful and inexpensive petroleum-based chemicals. In contrast to years past, today there is a lack of existing recycling and resource recovery options for the large quantity of tires disposed. Thus, tires have become a significant waste management problem. Waste tires constitute only about one-half of one weight-percent of the total municipal solid waste generated in California; however, due to their size, shape, and physical and chemical properties, they present an unusually challenging disposal problem.

Historically, waste tires were disposed of at solid waste landfills because tipping fees were low, or in stockpiles. Large numbers of the waste tires generated in southern California were disposed at several open pit mines. Once these operations were closed, landfill operators noticed that large volumes of whole tires were being disposed and they began raising tipping fees for whole tires. Some operators also began shredding whole tires or only accepting shredded tires for disposal. Recently, some landfill owners have sent out requests for proposals in search of alternatives to disposal (Bungay, 1991; Sheets, 1991).

Whole tires are expensive to bury in conventional landfills because they occupy volumes greater than their weight fraction would indicate. Shredding reduces the volume and eliminates other problems associated with landfilling and storage; however, the processing equipment is expensive to purchase and operate and consumes a great deal of energy. Shredding and storing or monofilling tires is a method to safely store this valuable resource; however, due to the large amount of tires available, it is doubtful that buried material would ever be economically recovered. As landfill operators have raised the fees for accepting whole tires (or refused to accept them at all), numerous and large stockpiles have developed. Improperly managed stockpiles present significant risks to the environment and public health. The risks arise from the potential for fires in tire piles and the harboring of disease vectors such as mosquitoes.

With landfill fees for disposing of whole tires increasing by as much as four times over the previous few years, there now exists a greater incentive than ever to stockpile or illegally dump waste tires. Illegal dumping and stockpiling are the least costly methods for an individual disposing of scrap tires. In the long run, social, environmental, and economic costs must also be considered; however, reasonable alternatives must be available in conjunction with restrictions on stockpiling. By considering regulations and markets together, a rational scrap tire management system can be created.

Many studies have concluded that the most suitable short-term approach to handling large volumes of scrap tires is energy recovery, at least until other forms of tire recycling become more economically attractive. The role that energy recovery will play in scrap tire disposal now and in the future is highly dependent upon development of other options for reuse or disposal and their associated costs.

## 1.1 PURPOSE AND SCOPE

The purpose of this report is to assess the feasibility of using tires as a fuel supplement to fulfill the reporting requirement of AB 1843 (PRC §42859). The report explores the technical, environmental, economic, geographical, regulatory, and institutional factors which may affect these uses. The options available are: reusing, retreading, exporting, processing (for producing new rubber products or material recovery), landfilling, stockpiling, and use as a fuel. To adequately assess the feasibility of using tires as fuel, the other uses of waste tires were also explored, as well as the issues surrounding each potential use.

### 1.1.1 Pertinent Legislation - Intent and Goals

#### California Tire Recycling Act - AB 1843

The California Tire Recycling Act was enacted in 1989 through Assembly Bill 1843 (Chapter 35, Statutes of 1990, now codified as Public Resources Code §42800 *et seq.*). It specifically addresses the special waste problem created by the generation and disposal of scrap tires. In developing AB 1843, the Legislature found that:

- California is currently faced with an existing waste tire inventory which grows by millions of tires each year. Without a dedication of resources to address the state's growing tire population, the health and safety of all Californians will be increasingly at risk.

- The problem posed by waste tire storage and disposal requires a comprehensive statewide response, including, but not limited to: reducing landfill disposal of whole tires; recycling of tires into secondary uses; and promoting secondary markets for waste tire by-products, tire shredding, and energy recovery.

- Waste tires represent a valuable state resource which should be reclaimed and recycled whenever possible. An abundance of tire recycling alternatives exists which have been demonstrated to be environmentally safe. These alternatives need to be promoted in order to achieve the maximum use of waste tires.

Under AB 1843, the California Integrated Waste Management Board (CIWMB or Board) is required to develop a permit program for waste tire facilities; create a tire recycling program; and report to the Legislature on the feasibility of using tires as a fuel supplement for cement kilns, lumber operations (including pulp and paper manufacturing), and other industrial processes.

Additionally, the Department of General Services is required to revise procurement specifications to allow for state purchases of products which are made of, or contain components which can be derived from, the recycling of used tires.

#### Integrated Waste Management Act - AB 939

In response to growing concern regarding the management and disposal of solid waste in California, the State Legislature passed Assembly Bill 939 (Chapter 1096, Statutes of 1989, now codified as PRC §40000 *et seq.*) known as the California Integrated Waste Management Act of 1989, which created the California Integrated Waste Management Board. The purpose of this legislation, in part, is to establish the hierarchy of waste management techniques of source reduction, reuse, recycling, and transformation. These techniques are to be practiced to the maximum extent feasible in order to conserve valuable resources and to divert solid wastes from our landfills. The Tire Recycling Act reflects this philosophy of integrated waste management by using a number of waste management practices together within a hierarchical structure to mitigate a specific solid waste problem.

#### Retreaded Tire Program - SB 1322

Senate Bill 1322 (Chapter 1096, Statutes of 1989, now codified as PRC §42000 *et seq.*) established state programs designed to reduce the amount of solid waste generated and disposed by state entities. Among these programs is the Retreaded Tire Program which specifies, in part, that the following activities take place in order to increase the use of retreaded tires, thereby decreasing the rate of waste tire disposal:

- The Board shall identify the obstacles to an increased market for retreaded tires.
- The Department of General Services and the Board shall adopt specifications which will designate the State minimum quality standards for retreaded tires. The specifications shall be designed to maximize the use of retreads by the State of California.
- All tires for use on state vehicles issued for short-term use through the Fleet Administration (except emergency vehicles) shall be equipped with retreaded tires.

#### Paving Materials - AB 1306

Assembly Bill 1306 (Chapter 35, Statutes of 1990, now codified as PRC §42700 *et seq.*) specifies that the Director of the Department of Transportation shall review and modify all bid specifications relating to the purchase of paving materials and base, subbase, and backfill materials. The standards and specifications shall provide for the use of recycled materials, including crumb rubber from waste tires, and shall not reduce the quality standards for highway and road construction. The Department of Transportation and any other state agencies which provide road construction and repair services are directed to make contracts available for those items which utilize recycled materials if the price of those items is competitive for the purposes intended.

#### Intermodal Surface Transportation Efficiency Act of 1991 - HR 2950

The Intermodal Surface Transportation Efficiency Act was enacted in December, 1991 through House of Representatives (HR) Bill 2950. Section 1038 of HR 2950 provides for the use of asphalt pavement containing recycled rubber.

The Secretary of the Department of Transportation (Secretary) and the Administrator of the Environmental Protection Agency (Administrator) are directed to coordinate and conduct, in cooperation with the states, a study to determine: the threat to human health and the environment associated with the production and use of asphalt pavement containing recycled rubber; the degree to which asphalt pavement containing recycled rubber can be recycled; and, the performance of the asphalt pavement containing recycled rubber under various climate and use conditions.

The Secretary and the Administrator are required to submit a report to Congress within 18 months on the results of the studies, including a detailed analysis of the economic savings, the technical performance qualities, and the environmental benefits of using such recycled materials in terms of reducing air emissions, conserving natural resources, and reducing disposal of the materials in landfills. The Secretary is directed to encourage the use of recycled materials determined to be appropriate by the studies in federally assisted highway projects.

Beginning on January 1, 1995, and annually thereafter, each state must certify to the Secretary that it has satisfied the minimum utilization requirement for asphalt pavement containing recycled rubber. The requirement for asphalt pavement containing recycled rubber (as a percentage of the total tons of asphalt laid in the state and financed in whole or part by federal funds) shall be five percent for the year 1994, increasing by five percent per year to twenty percent for the year 1997 and each year thereafter.

The requirement for asphalt pavement containing recycled rubber may not be met by any use or technique found to be unsuitable for use in highway projects by the studies. The Secretary may also set aside the requirements depending upon the results of the study.

### 1.1.2 Scope of Work

This report is on the feasibility of using waste tires as a fuel supplement for cement kilns, lumber operations, and other industrial processes. It has been written in consultation with the California Air

Resources Board (CARB) and the California Energy Resources Conservation and Development Commission (CEC) to fulfill the reporting requirement of AB 1843 (PRC §42859). An assessment of air quality impacts from the combustion of waste tires, the identification of impediments to the utilization of waste tires, and recommendations to encourage greater utilization of waste tires are presented. A comparison of waste tires to other fuels is made to highlight the value of tires as fuel, and to assist in determining which industrial processes may be appropriate for using tires as fuel. Estimates of the numbers of waste tires generated and disposed of by Californians are developed to quantify the problem. Current and potential waste tire consumption by various alternative uses is examined to determine the role these uses could play in the management of scrap tires.

### 1.1.3 Report Organization

The remainder of Section 1 presents background information on the waste tire problem including: an estimate of the waste tire generation rate in California; a description of the properties of tires which make them a difficult waste to dispose of; and a discussion of related environmental issues. This is followed by comparisons of the fuel characteristics of waste tires to municipal solid waste (MSW) and other fuels.

Scrap-tire alternative uses are discussed in Section 2. The discussion follows the order established in the waste management hierarchy of AB 939 and highlights the importance of source reduction and reuse as primary methods for reducing the number of waste tires generated and requiring disposal. Alternative uses of whole tires, shredded and chipped tires, crumb rubber and tire buffings are described to include the following: crash barriers and dock bumpers; erosion control; road base, Rubber-Modified Asphalt Concrete (RUMAC) and Asphalt-Rubber (AR), and roofing; fabricated rubber products and flooring; a soil amendment and composting medium; and finally a fuel supplement.

Section 3 is a discussion of the impediments to the use of waste tires. The potential impacts of various waste-tire uses are addressed, including air pollution from transportation, processing and combustion equipment; wastes and by-products; product quality concerns; economic issues in comparison with competing processes and products; and siting and permitting issues associated with the use of tires as fuel.

Options for Mitigating the Waste Tire Problem are presented in Section 4. The methods examined for overcoming impediments to the use of waste tires include the following: increased research and development; technology transfer; quantification of environmental impacts through demonstration projects; market development and economic incentives; and improving public awareness and education. Conclusions and recommendations derived from this study are also presented. Options for the use of waste tires are compared based upon the projected degree of mitigation of the waste tire problem, product quality as compared with competing materials, potential health and environmental impacts, and process and economic feasibility.

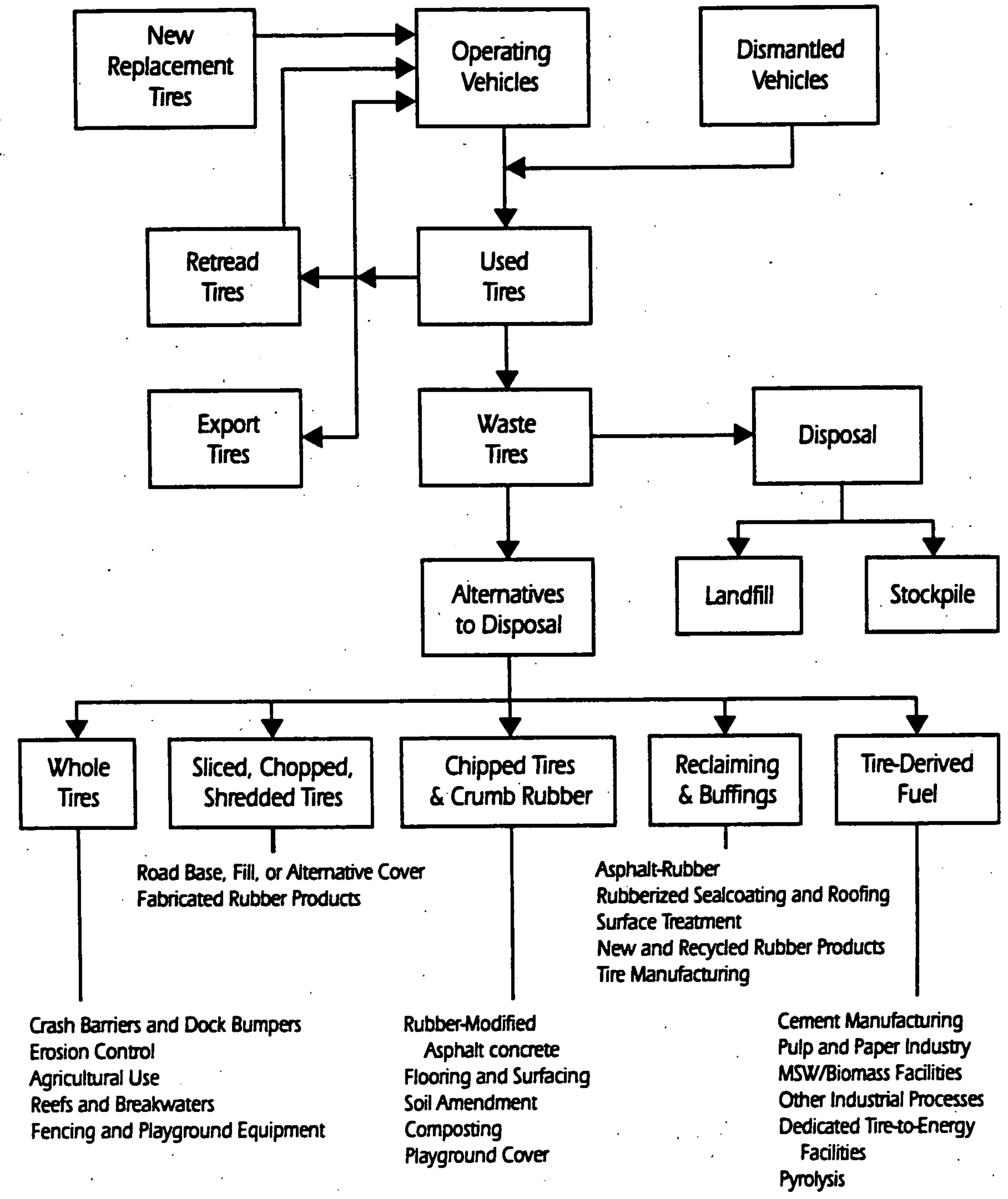
## 1.2 BACKGROUND

Definitions for the terms used in this report are necessary because no consistent use of terminology was found in the references or sources of information consulted during preparation of this report. Many of the terms can be found in the glossary. For consistency and clarity, used tires and waste tires were defined as follows. A *used tire* is defined as any tire that has been removed from the wheel of a vehicle, including tires that may be reused as a vehicle tire, or retreaded, depending on the condition of the tire. A used tire that is not reused, exported or retreaded becomes a *waste tire* which is defined as a tire that is no longer suitable for its original intended use or for repair due to wear, damage, or defect.

The generation, use, and disposal of scrap tires can be presented diagrammatically because the sources and options for reuse, recycling, and disposal are discrete. Figure 1-1 presents a flowchart for illustration of scrap tire management, and as such, represents an outline of the structure of this report. New tires or retreaded tires replace used

**FIGURE 1 - 1**

SCRAP TIRE GENERATION, USE AND DISPOSAL



tires on operating vehicles. Tires from dismantled vehicles are added to the pool which is processed by individual dealers or tire jockeys to recover tires which may be reused or retreaded. Some used tires are also exported for reuse, retreading, or other alternatives. The remaining pool of waste tires (as defined) which are not recovered for alternative uses require disposal. The alternatives to disposal have been organized into the five categories as shown in Figure 1-1. These alternative uses of whole tires -- sliced, chopped and shredded tires; chipped tires and crumb rubber; reclaimed rubber and buffings; and tire-derived-fuel -- are discussed in Section 2.

### 1.2.1 Quantification of Problem

Quantifying the number of waste tires generated in California is a difficult task to accomplish. Direct quantification by simply counting all of the tires coming off of vehicles, or counting the tires going to landfills and stockpiles is impossible for two major reasons. The first is that there are literally thousands of tire supply, installation and repair facilities, and disposal sites. The second is that very few of the site operators keep accurate records for the number of waste tires entering or leaving their premises.

It is also difficult to get accurate information from organizations that are in the tire business, such as the National Tire Dealers and Retreaders Association (NTDRA), the Tire Retread Information Bureau (TRIB), the Rubber Manufacturer's Association (RMA), and the major tire companies. These organizations have data for new tire shipments, tires imported and exported, and the number of tires retreaded on a national basis only. Tire manufacturers are not willing to give information on sales or shipments for proprietary reasons.

The California Department of Commerce does not have statistics available on vehicle tires imported to or exported from California. The California World Trade Commission compiles port trade and state export data; however, these are only a measure of port activity which is significantly affected by the transhipment of goods to and from other states, and thus, are not representative of California's net trade.

The EPA and the tire industry in general agree on a standard "rule of thumb" for estimating the generation rate of used tires (US EPA, 1991). The rate is proportional to the population and assumed to be approximately one used tire per person per year; therefore, on a population basis, the estimated number of used tires generated in 1990 for the United States and California was 250 million and 30 million, respectively.

The following methodology outlines the assumptions and information that were used to produce estimates for California used tire and waste tire generation rates, and waste tire alternative use and disposal rates:

- The number of *used* tires (tires removed from vehicles) generated is equal to the sum of new replacement tires, reused tires and retreaded tires installed onto vehicles, and tires removed from dismantled vehicles.

- The number of *waste* tires generated is equal to the number of used tires generated minus the number of used tires which are reused, retreaded, and exported.

- The average passenger vehicle and light-truck waste tire (light-duty tire) weighs 18 pounds. A value of 20 pounds per light-duty tire is the commonly accepted value; however, based on data from actual tire handling systems and various process feed systems, the actual value may be closer to 18 pounds. The average "other truck" and bus-waste tire (heavy-duty tire) weighs 100 pounds (Bungay, 1991; Lockington, 1991; Sheets, 1991).

- National data for new replacement tires shipped for domestic use, including imports (RMA, 1990) and tires retreaded (NTDRA, 1990; TRIB, 1990), were multiplied by the ratio of California to total United States vehicle miles traveled (Motor Vehicle Manufacturer's Association Facts & Figures for 1990) to produce an estimate of the number of new replacement and retreaded tires used in California annually. Tire industry experts have suggested that the percentage of California light-duty tires that are retreaded is substantially less than the national average. This calculated value, therefore, has been reduced by 50 percent.

- The number of used light-duty tires exported is an approximation based on industry contact information. Used heavy-duty tires which are exported are assumed to account for five percent of the used tires generated.

- The number of tires removed from dismantled vehicles is estimated based upon California Department of Motor Vehicle records which indicate that approximately 50,000 vehicles were classified as "non-revivable junk" for the twelve-month period ending July 1991. No information was obtained regarding vehicle types; therefore, the pool of scrapped vehicles is assumed to be similar in composition to the pool of operating vehicles.

- The consumption of light-duty tires by alternative uses is based primarily on information obtained from cement manufacturing companies and Oxford Energy Company's Modesto Energy Project. Other miscellaneous uses of these tires is minimal. Tire industry experts have indicated that the majority of the available heavy-duty tires reach alternative-use markets; however, estimates of the actual numbers could not be determined.

- Motorcycle, tractor, and industrial tires have been excluded from this analysis. Waste motorcycle tires may exceed one-half million annually. Waste tires from tractors and industrial vehicles may also exceed a combined one-half million per year, many of which are retreaded.

Based on the assumptions above, estimates of the number of tires generated, retreaded, reused, exported, and disposed of in 1990 are shown in Figures 1-2 and 1-3. About 23.4 million light-duty used tires and 3.6 million heavy-duty used tires were generated in 1990. Of the 19.5 million light-duty waste tires, an estimated 14.5 million (62 percent of the used tires generated, or 130,000 tons) are disposed of annually. Approximately 1.4 million heavy-duty waste tires are generated annually. The portion of these that is disposed of has not been determined; however, 50 percent (0.7 million heavy-duty tires, or 35,000 tons annually) is considered to be a reasonable estimate. A total of approximately 165,000 tons of waste tires, therefore, are disposed of annually in California landfills and stockpiles, or illegally dumped.

At least another 32 million tires have been identified as stored in stockpiles across the state. The number of stockpiled tires which are of concern may be as low as 20 million, because the largest stockpile in the state is dedicated to the Oxford Energy Facility. Tires which have been in stockpiles for some time tend to be contaminated with dirt and rock and can be difficult to process in shredders. The composition of older tires is also different or the tires have been oxidized or otherwise damaged by exposure to the elements. Often, the simplest and least costly approach is to combust them whole; therefore, in the discussion of recycling, newly generated waste tires are the principal focus.

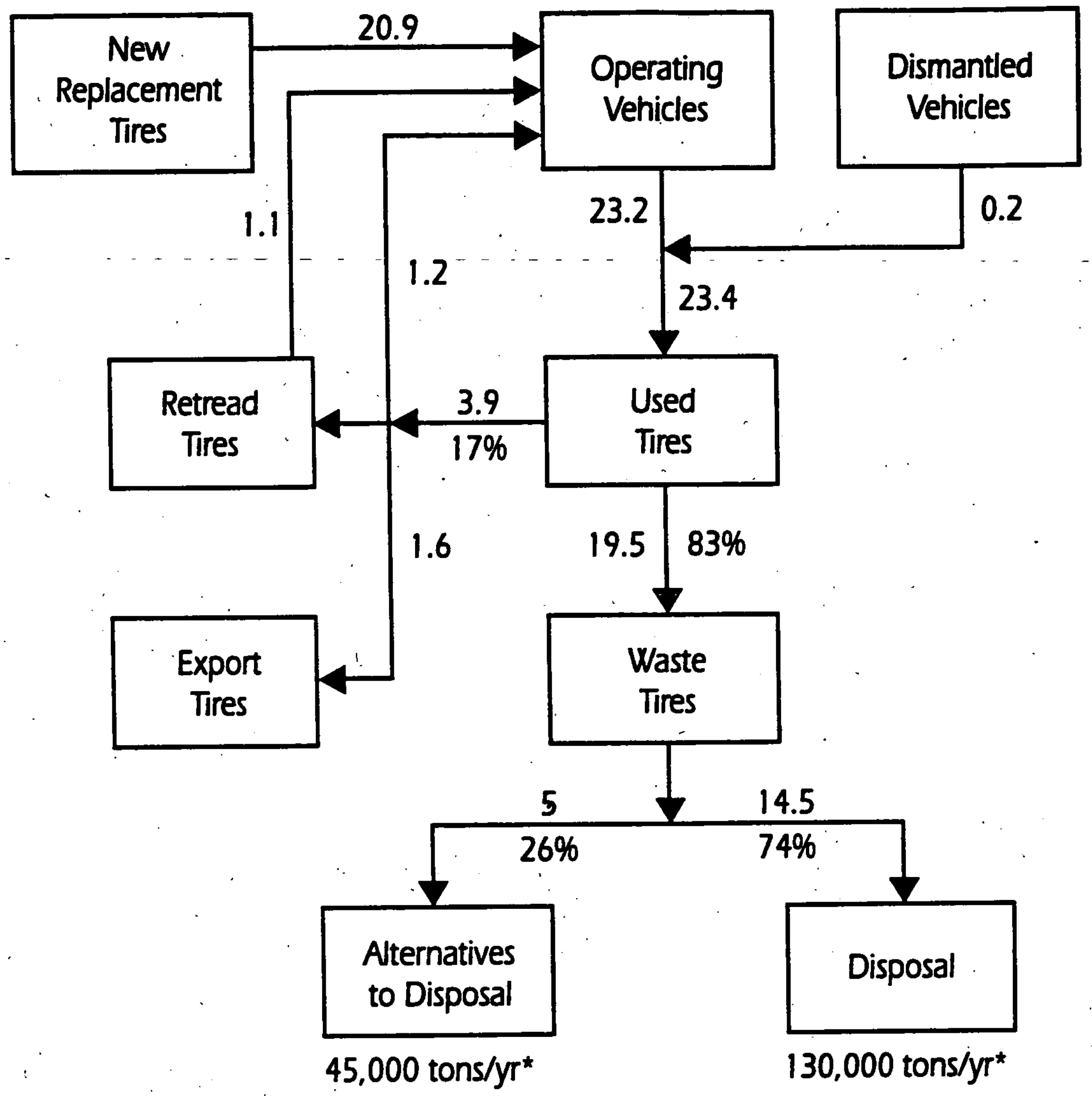
### 1.2.2 Properties of Tires and Related Environmental Problems

#### Tire Properties

The properties which make tires so durable also make them a very special waste disposal problem. Some specific properties are the resistance to thermal breakdown, wear, and biodegradation; and the ability to withstand the elements including ultraviolet radiation, ozone and other oxidants, water and ice. A tire only becomes a waste tire because either the tread has worn off or it has become physically damaged and is therefore no longer usable. The majority of the materials from which tires are made — rubber, steel, fiber-

**FIGURE 1 - 2**

QUANTIFICATION OF WASTE TIRE GENERATION, USE AND DISPOSAL
LIGHT-DUTY (1990)
(millions of tires per year)




*Based upon 18 pounds per waste tire

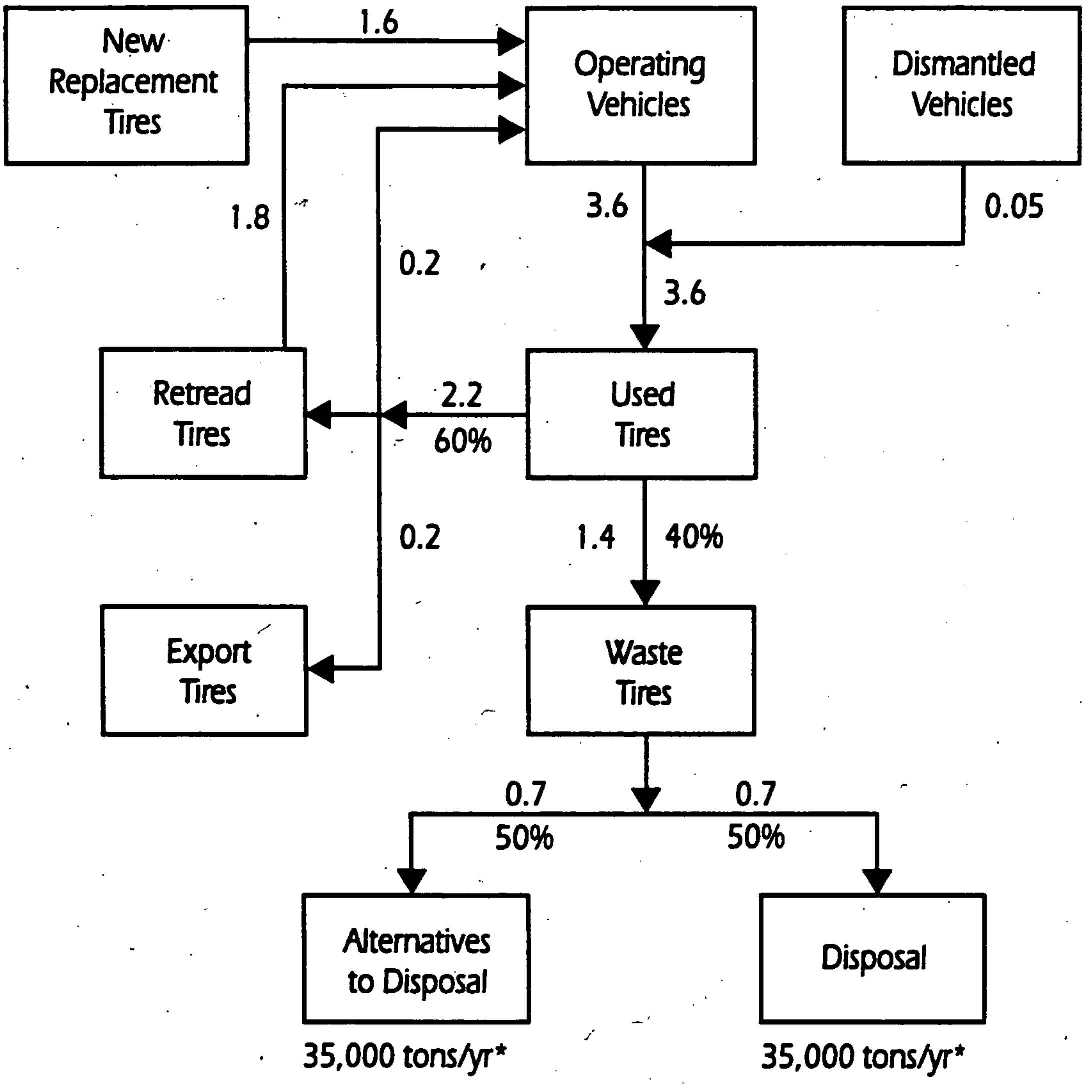
Notes:

Light-duty tires are defined as those from passenger vehicles and light-duty trucks, typically ranging in weight from 12 to 30 pounds.

Waste tires from motorcycles may exceed 0.5 million annually and are not included.

**FIGURE 1 - 3**

QUANTIFICATION OF WASTE TIRE GENERATION, USE AND DISPOSAL
HEAVY-DUTY (1990)
(millions of tires per year)




*Based upon 100 pounds per waste tire

Notes:

Heavy-duty tires are defined as those from medium and heavy-duty trucks and buses, typically ranging in weight from 80 to 140 pounds.

Waste tires from tractor and industrial vehicles may exceed 0.5 million annually and are not included.

glass, and fabric — remain essentially the same as the day the tires were assembled (Fader, 1990).

Tire manufacturers use many different rubber compounding formulas for various applications, but they all include natural and synthetic rubbers, carbon black, sulfur, zinc oxide, and various extenders and anti-oxidants. Generally, an average of 25 to 30 percent of the rubber used for modern radial tires is natural rubber, with the balance being synthetic. The rubber used in modern aircraft tires is 100 percent natural rubber (Fader, 1990; Zimmer, 1991). Natural rubber is an elastic, waterproof material obtained from several species of tropical trees. Synthetic rubber (primarily styrene butadiene copolymer or SBR) is produced from petroleum. Rubber is an excellent electrical insulator, and is the most elastic substance known (Wang, 1985).

The physical characteristics of tires make them difficult to store and transport. Tires are bulky and rigid; consequently, they are not easily compressed or packed together and require large volumes of space when stored or transported in whole form. A solution to this problem is to shred or chip whole tires to reduce their volume; however, powerful machinery is required to overcome the strength and resiliency of the rubber and steel.

## Environmental Problems

Whole tires, when disposed of in landfills, consume a disproportionate amount of landfill space. When whole tires are disposed of in bulk, 50 to 75 percent of the space they occupy is void. The voids introduced with tires can store air and trap landfill gases which increase the risk of landfill fire. A common problem at landfills is that whole tires tend to rise or "float" to the surface of a landfill due to their buoyancy compared to the surrounding wastes and soil. As a result, tires may penetrate the final cover following the closure of the landfill. Also, air voids within a group of whole tires can ultimately result in differential settlement of the final landfill cover which may lead to pooling of water, excessive infiltration of water into the landfill, and formation of leachate. Careful planning and special handling techniques such as deep burial, placing heavy wastes such as concrete rubble over the tires, or mixing with other wastes rather than placing tires together are often required by landfill operators to reduce the likelihood of these occurrences. Shredding, chopping, or slicing the tires prior to burying can reduce or eliminate these problems. Special attention to tires results in higher tipping fees or refusal by landfill operators to accept whole tires, and serves as a driving force to handle tires in a less expensive way, namely stockpiling.

Stockpiling is a common method for handling waste tires; however, it presents potential environmental impacts. Whole tires can collect and retain water, and as a result, may become a haven and breeding ground for mosquitoes, rodents, and other carriers of disease. California has an arid to semi-arid climate and does not have a significant mosquito problem. In addition, tires are highly combustible, and when stockpiled whole, multiple pathways exist through which an unlimited amount of oxygen is supplied for combustion.

According to the EPA, more tire stockpiles and illegal dumps are coming into existence nationally, and with them the occurrence of tire fires. These fires, most often started by arson, generate a large amount of heat, and virtually every tire in the pile has access to air, making them extremely difficult to extinguish. Some tire fires have continued for months. For example, the 1983 Rhinehart tire fire in Frederick County, Virginia, burned five to seven million tires over the course of nearly nine months. Open, uncontrolled combustion of tires generates smoke (carbonaceous particulates), and toxic air pollutants including benzene and polynuclear aromatic hydrocarbons. The intense heat generates pyrolytic oil that becomes mixed with the water used to fight the fire. The oil may then contaminate surrounding soils, surface waters, and ground water (Weddle, 1990).

Shredding, chopping, or slicing tires prior to stockpiling eliminates many of the environmental problems associated with stockpiling whole tires. An alternative stockpiling method for whole tires is currently in practice by Tire Salvage, Incorporated of North Haven, Connecticut. Whole tires have been dumped since 1977 into an abandoned 30 acre clay quarry filled with water called "The Tire Pond." The tires are kept submerged so that mosquitoes, other pests, and fires are avoided (Tire Salvage, Inc., 1990).

### 1.2.3 Perspective

#### Comparison to Municipal Solid Waste

Waste tires represent only about six tenths of one percent (0.6 percent) of the total California MSW on a weight basis. Whole tires, however, occupy a considerably larger fraction on a volume basis. Approximately 10 to 15 whole tires may occupy one cubic yard of volume when buried together. Assuming an average weight of 18 pounds per light-duty tire, this results in an in-place density of 180 to 270 pounds per cubic yard (lb/yd$^3$). Well compacted MSW in landfills has an average density of about 1000 lb/yd$^3$. Waste tires, therefore, would account for approximately 2.7 percent of MSW on a volume basis if all waste tires were monofilled whole or buried together in clusters.

By shredding whole tires or reducing their volume in other ways, the volume which they occupy may be reduced by as much as 75 percent. This decreases transportation costs to the disposal site, increases the in-place density to 1000 lb/yd$^3$ or greater, and precludes the tire buoyancy phenomenon. Shredding, however, requires a significant amount of energy. This is discussed in Section 3.1.2 (Higgins, 1987).

#### Energy Comparison

As a fuel, waste tires are an excellent energy resource. Tires have a heating value of 12,000 to 16,000 British Thermal Units per pound (BTU/lb), depending on the composition and whether or not the steel has been removed. For the purposes of this report, the average heating value of tires or tire-derived-fuel is assumed to be 14,000 BTU/lb. Bituminous coal has values ranging between 11,000 and 13,000 BTU/lb. Table 1-1 presents typical heating values and moisture and sulfur contents for waste tires and several other fuels for comparison. Tires contain three times the heating value of MSW, and two to three times the heating value of most types of biomass. Tires used as fuel, whether in whole or volume-reduced form, have a negligible moisture content (generally less than 2 percent, compared to between 15 and 40 percent for MSW). Tires contain less sulfur (1 to 2 weight percent) — an element which is oxidized upon combustion and released as a criteria air pollutant — than most eastern coals (1.5 to 4 weight percent). Some western (low sulfur) coals, however, have sulfur concentrations of 0.4 to 1.0 weight percent. Additional information compiled by the CARB on the elemental analyses and heating values of tires, western coal, MSW, refuse-derived-fuel (RDF), and biomass is given in Appendix A.

According to the CARB, a gasoline-powered passenger vehicle operating in California in 1991 will travel about 33 miles per day with a fuel economy of 22 miles per gallon (CARB, 1991a). This requires the consumption of about one and one-half gallons of gasoline per day per vehicle — an energy use of 184,800 BTU. With an energy content of approximately 250,000 BTU, a single 18 pound tire contains the energy equivalent to about two gallons of gasoline, or the energy required to operate a passenger vehicle for about one day.

The Oxford Energy Company's Modesto Energy Project produces 14 megawatts (MW) of electrical power from the combustion of four and one-half to five million tires per year — enough to supply the electrical needs of about 14,000 homes (Oxford Energy Company, 1990; Wallace, 1990). The electrical requirement of an average home (24 Kw-hrs per day, which is equivalent to keeping ten 100 watt light bulbs on for 24 hours) can be met by the electrical energy produced from the combustion of one tire per day.

**TABLE 1 - 1**

COMPARISON OF FUEL CHARACTERISTICS

| Fuel | Moisture (% by wt) | Sulfur (% by wt) | Heating Value (BTU/lb) |
|---|---|---|---|
| Waste Tires | 0.3-2 | 1-2 | 12,000-16,000 |
| Coal | | | |
| anthracite | 2-5 | 0.5-1.7 | 12,000-14,000 |
| bituminous | 3-10 | 0.4-3.0 | 11,000-13,000 |
| subbituminous | 18-23 | 0.3-0.4 | 9,000-11,000 |
| lignite | 30-40 | 0.5-0.7 | 7,000-8,000 |
| Petroleum Coke | 0.5-1 | 0.8-1.0 | 12,500-15,000 |
| No. 6 Fuel Oil | - | 0.7-3.5 | 18,000-18,500 |
| MSW | 15-40 | 0.1-0.5 | 3,500-5,500 |
| Typical RDF | 10-25 | 0.2-1 | 5,200-7,300 |
| Newspaper | 6 | 0.05-0.2 | 7,975 |
| Corrugated Paper | 5 | 0.05-0.2 | 7,400 |
| Sawdust | 7-10 | 0-0.2 | 7,800-9,600 |
| Hogged-Fuel (Wet Wood) | 10-60 | 0-0.2 | 4,000-5,500 |
| Agricultural Wastes | 5-30 | 0.01-0.7 | 5,000-8,500 |

Source: CIWMB files

One barrel of oil (42 U.S. gallons) has an energy content of approximately 5.88 million BTU. California is currently disposing of about 150,000 tons of tires annually, and with them, a potential 4.2 trillion BTU of energy which is equivalent to more than 700,000 barrels of oil (1,960 barrels per day). This wasted fuel has the potential to provide energy equal to that supplied by about two percent of the total crude oil currently imported by California (NEOS Corp., 1991).

## 1.3 SIGNIFICANT BENEFITS OF REMEDIATION

By disposing of about 15 million tires per year, California is throwing away a valuable energy and material resource. Waste tires can be used to supplement or replace fossil fuels such as coal, petroleum, and natural gas (where technical, environmental, and economic feasibility permit), thereby decreasing consumption of these non-renewable resources. The rubber, carbon black, and extender oils from which tires are constructed are derived largely from petroleum resources and may be reused for some applications, again decreasing the use of non-renewable resources. The steel belts and bead wire from waste tires can be recycled, thus decreasing consumption of natural resources.

Energy and materials can be recovered from the waste tires currently generated and the estimated 30 million tires in registered California stockpiles. Recovering tires from stockpiles not only benefits California by providing a valuable resource, but also eliminates the environmental hazards associated with whole tire stockpiles.

Landfilling tires (especially whole tires) consumes valuable landfill space. Reusing and recycling waste tires to a greater extent diverts tires from disposal. For those waste tires which are landfilled, shredding or some other form of volume reduction should be employed to minimize the landfill space they occupy. Shredded-tire monofills and stockpiles are options to traditional disposal which allow for future recovery of the tire materials. Due to the contamination with dirt and the large amount of tires available, however, it is doubtful that buried material would ever be economically recovered.

# Section 2

## Abatement and Alternative Uses

There are many options for decreasing the number of waste tires which will require eventual disposal. The options include source reduction, reuse, export, retreading, various alternative uses, and use as a fuel. These uses and their current and potential consumption of waste tires are discussed in this section.

### 2.1 SOURCE REDUCTION, REUSE, AND EXPORT

Among the abatement and use alternatives, source reduction is unique in that every vehicle user can help. Source reduction includes improved tire maintenance, reduced driving, reduced tire misuse, and purchase of long-mileage tires, all of which extend the mileage obtained from tires. Although these techniques for source reduction are currently in practice, they are not being used to their full potential.

#### 2.1.1 Source Reduction

Obtaining the maximum mileage from an automobile tire requires proper care and maintenance. Three key factors affecting tire life are tire pressure, driving speed, and general preventive maintenance.

Improper inflation can significantly decrease tire life. An underinflated tire flexes more and generates more friction with the road, producing higher temperatures and greater wear. Overinflated tires, which are more vulnerable to penetration than properly inflated tires, can also cause premature tire failure as well as excessive wear (Aguirre, 1987). Driving speed also has an effect on tire wear. Tire flex, along with tire temperature, increases as automobile speed increases. Ply separation, a problem also associated with higher temperatures and speeds, leads to premature tire failure. Also, excessive cornering speeds and abrupt starts and stops lead to increased tire wear or failure. In some cases, the tire casing is often damaged or destroyed, prohibiting retreading.

Neglecting to periodically rotate the tires, balance the wheels, maintain wheel alignment, or replace worn shocks or struts leads to increased tire wear (*Automotive Fleet*, 1989). Neglect of road maintenance can also lead to increased tire wear and tire damage, possibly resulting in the destruction of the tire casing.

Another option for reducing the number of waste tires generated at the source is to decrease use of automobiles or increase public transit and ridesharing. This is the same principal used for reducing gasoline consumption and automobile emissions.

Source reduction can also be accomplished directly at the tire manufacturing facility. If tires could be designed for greater mileage, then the number of tires purchased and the number requiring disposal would decrease; however, further extensions of design life would compromise performance. The recent industry trend has been to emphasize greater performance characteristics.

#### 2.1.2 Reuse

Another option for used tire abatement is reuse. Reuse of tires postpones sales of new tires and lowers waste tire generation rates.

Used tires may be resold or reused depending on the amount of legal tread remaining. By applying this method of used tire reduction, the maximum lifetime of each tire may be attained. Many of the tires that could be reused, however, are often retreaded (Burgess and Niple, and Waste Recovery, Inc., 1987).

### 2.1.3 Export

Tire exportation is an option for reducing the number of waste tires being stockpiled and landfilled in California. In the past, about 1 to 1.2 million waste tires per year have been exported to Mexico from California mostly for reuse (Lockington, 1991). In the future, tire rubber is expected to be exported to Mexico only for use as a fuel supplement at a cement manufacturing facility in Ensenada. Approximately one million tires will be exported from southern California each year. The tires will be either shredded, quartered, halved, or baled to reduce transportation costs. Another cement manufacturing facility located in Hermosillo could use as many as five million tires per year for fuel — tires which could potentially be exported from southern California as well (Stevens, 1991).

Tires may be exported to Nevada for use as a fuel at a tire-to-energy facility that is planned for the township of Moapa, Nevada. According to the Oxford Energy Company, the plant would combust 18 million tires per year, 15 million of which would need to be imported, 8 to 10 million of which would come from the Los Angeles area alone (Oxford Energy Company, 1990).

## 2.2 RETREADING

Retreading tires reduces the number of waste tires requiring disposal by reusing the tire casing. Retreaded tires are generally 30 to 50 percent less expensive than new tires (although some imports are comparable in price) and also consume less petroleum during manufacturing. According to the Tire Retread Information Bureau (TRIB), manufacture of a new passenger vehicle tire requires seven gallons of petroleum compared to two and one-half gallons needed for a retreaded tire — a net savings of four and one-half gallons. Comparatively, retreading a truck tire saves about 15 gallons of oil. The number of retreaded tires sold on a national basis has declined due in part to inexpensive domestic and imported new tires and to the low demand for the types of tires retreaded (primarily passenger tires). In 1989 over 35 million retreaded tires were sold nationally, which declined to about 33 million in 1990. Retreaded truck tires accounted for approximately 45 percent of the total retread sales during these years. The decline in sales has contributed to an increasing number of tires requiring disposal (TRIB, 1990).

## 2.3 ALTERNATIVES TO DISPOSAL

Landfilling and stockpiling are currently the major methods of disposal for waste tires. Many alternatives to disposal exist and are currently practiced or are being demonstrated. These alternative uses (refer to Figure 1-1) of whole tires, chopped and shredded tires, chipped tires and crumb rubber, and buffings and reclaimed rubber are discussed in this section. The fuel related uses are discussed separately in Section 2.4.

### 2.3.1 Whole Tires

Whole waste tires may be used in many different applications including crash barriers and dock bumpers, erosion control, agriculture, reefs and breakwaters, and fencing and playground equipment. Most whole tire alternatives use the complete tire without producing secondary waste.

#### Crash Barriers and Dock Bumpers

Whole tires are currently being used for highway crash barriers, boat docks and truck unloading docks. Tests at the Texas Transportation Institute have shown that because of the energy-absorbing property of highway abutments made with waste tires, the risk of fatality and injury is reduced (Crane, et al., 1978). Similarly, waste tires used to line boat and truck docks cushion minor impacts.

#### Erosion Control

Another alternative use for whole tires is erosion control. Currently, the California Department of

Transportation (CalTrans) is using waste tires for shoulder reinforcement on roadways and for slope stabilization in drainage canals. Both types of construction have proven to be stable and economical. Whole tires have also been used by CalTrans to control sand drifts in desert areas (CalTrans, 1990; Juarez, 1988).

### Agricultural Use

The agricultural industry uses whole tires to weight down tarpaulins covering large piles of farm-related products. Tires may also be split to avoid water collection or bored with holes to provide drainage.

### Reefs and Breakwaters

Whole tires have been used in Florida, Oregon, and New Jersey to construct artificial reefs. It has been demonstrated that tire reefs can be beneficial to aquatic life by providing a habitat. It has yet to be proven if tire reefs pose a significant threat in marine environments (Recycling Research, Inc., 1990; Stone, et al., 1979). Although tires are durable and tire reefs can last indefinitely, installing a tire reef is more labor intensive than other types of artificial reefs (e.g. rock or concrete rubble) because the tires need to be bound together, submerged and properly moored (Burgess and Niple, and Waste Recovery, Inc., 1987; Juarez, 1988). Potential problems with tire reefs are their instability in strong currents and the leaching of metals into the marine environment.

Breakwaters, used to reduce shoreline erosion and provide a habitat for aquatic life and marine fowl, have also been constructed using tires. Unlike tire reefs, however, tire breakwaters are inexpensive and easy to manage (Recycling Research, Inc., 1990).

### Fencing and Playground Equipment

Several miscellaneous uses for whole waste tires include livestock fencing and playground equipment. Saf-T-Fence, a New Jersey-based company, has manufactured fences using non-steel belted tires. The fences are less expensive to install and are safer for animals. Tire Playground, Inc., also a New Jersey-based company, has designed and constructed playground equipment using whole tires. Only non-steel belted tires are used (only five percent of the tires manufactured today are non-steel belted) and costs are less than its lumber equivalent (Sikora, 1986).

The aesthetics of tire fences and playground equipment is an issue which merits discussion. The use of waste tires in this manner would probably not be acceptable in all communities. This issue, among others, would need to be addressed when planning such a use.

### Assessment

Whole tires have performed well in several of these types of applications without producing any secondary waste; however, eventual disposal may also be required. There has been, and will continue to be, a limited consumption of tires for these uses, partly due to tire durability. Potential consumption for these applications is also difficult to estimate because the use of tires is site specific. For California, however, these uses have a low potential to consume a large quantity of waste tires.

## 2.3.2 Sliced, Chopped, and Shredded Tires

Due in part to the emergence of the waste tire problem, many types of processing equipment (and services using the equipment) are currently available. Whole tires can be sliced into circular halves, chopped into two or more pieces, or shredded.

A tire shredder is composed of a diesel engine or electric motor which drives two sets of counter-rotating steel shafts. Cutting blades are positioned on both of the shafts, opposing each other. Whole tires are manually positioned on an automatic conveyance system, which carries and drops the tires into the cutting blades. The tires are shredded while being pulled through the blades and the resulting shreds are deposited on a second conveyor.

Several potential alternatives exist for shredded tire use such as roadbase, fill, and alternative landfill cover.

### Road Base, Fill, or Alternative Cover

A recent study conducted for the Minnesota Pollution Control Agency on the use of shredded tires as a sub-grade road bed (road base) has shown that metals and polynuclear aromatic hydrocarbons (PAH) can leach from shredded tires. It was also shown, however, that asphalt exhibits similar or higher concentrations of leached metals and PAH. Shredded tires were substituted for the traditional wood chips and sawdust normally used for light-weight fill material in wetland areas. Organic material, however, is biodegradable, and with time, settling can occur. Tire rubber degrades very slowly and should remain stable for at least the expected lifetime of the road. Except for potential leaching impacts, the few test applications have shown promise (Twin City Testing Corp., 1990).

Shredded tires have also been used for fill in other applications as well as for alternative landfill cover. The Islip town landfill in Hauppauge, New York, is currently using a four-to-one mixture of soil and chipped tires (two inch) for daily cover. Approximately 66 tons of chips are used each day. This use has been permitted by the New York State Department of Environmental Protection (Recycling Research, Inc., 1990).

### Fabricated Rubber Products

Stampings are products which are die-cut from whole tire casings and sidewalls. Lakin General Corporation processes over 200,000 tires annually at its Chicago facility, producing items such as tail pipe hangers, snowblower blades, and conveyor rollers (Gust, 1991). F & B Enterprises, a New England-based company, also produces stamped products including muffler hangers and forklift tires. Approximately 4,000 tires a day are split, yielding strips which are flattened and die-cut into the required shapes. The whole tire casing is used except for the steel bead wire (Sikora, 1986; Sladek, et al., 1989).

The Tire Pond Inc., located in North Haven, Connecticut, manufactures "woven" floor mats from non-steel belted tires. Tires are debeaded, cut into one-half to three-quarter inch strips, punched with holes, and cut to the appropriate length. The strips are then "woven" with wire into mats. Approximately two mats are manufactured from every tire processed. Current production is about 5,000 mats per year (Rizzo, 1991). There is little waste because the entire casing is used.

### Assessment

Precautions against potential leaching of metals and PAH must be considered for uses in contact with soils. The suitability of shredded or chipped tires for alternative landfill cover, roadbase, or fill needs to be demonstrated in California before an assessment or determination can be made. These alternatives could conceivably use a large quantity of tire rubber, although it would not be easily recoverable for future use.

Because there is a limited market for stamped products, and only non-steel belted tires are used, it is unlikely that this application can consume a significant amount of tires.

## 2.3.3 Chipped Tires and Crumb Rubber

Whole tires can also be "shredded" into chips and crumb rubber using a tire shredder. Classifiers ("screens" used to pass or collect material depending on the size) may be used to sort material from a previous pass of the cutting blades and route it back for further processing. This continues until the material is reduced to the selected size and has passed through the classifier. Some shredding systems use multiple sets of cutting blades to reduce the size of the material rather than using classifiers. For the purposes of this report, crumb rubber is defined as particles of rubber from one-eighth inch to about one-half inch in size. This definition was selected because of the inconsistency among the sources of information used for this report.

### Rubber-Modified Asphalt Concrete

A promising alternative for using waste tire rubber, in the form of crumb rubber, is RUMAC (also known as the dry process). The two types of RUMAC are Plusride™ and the Generic Process, developed by BAS Corporation. Both processes incorporate crumb rubber as a partial substitution for aggregate. Approximately three to four percent crumb rubber by weight or 8,000 to 12,000 tires per mile of two-lane, three-inch lift roadway are used in RUMAC. Due to licensing costs associated with a patented process, Plusride is more costly than the Generic Process (BAS Corp., 1991); however, both processes are more expensive than conventional asphalt due to the additional cost of the tire rubber, the lack of contractor experience, and the limited use to date (BAS Corp., 1991; Chamberlin, et al., 1986; Kearny, 1990). The Generic Process is also less expensive than Asphalt-Rubber systems because there is no need for specialized equipment such as blending units and storage tanks. RUMAC has been shown to be cost effective in some cases. It can be laid thinner, can have reduced maintenance costs in some instances, and can have a longer life than conventional asphalt. In widespread use, RUMAC could prove to be economical (BAS Corp., 1990; Van Kirk, 1989).

CalTrans began experimenting with RUMAC materials in 1978. Since then, many test projects have been constructed and evaluated. Some projects demonstrated that thinner sections of RUMAC can outperform thicker sections of conventional asphalt concrete; however, because some projects are still in service and individual RUMAC sections have not yet failed, the cost-effectiveness is difficult to determine. Paving specifications for RUMAC, therefore, cannot be determined until these projects are complete.

RUMAC has generally outperformed conventional asphalt (US EPA, 1991). According to CalTrans, laboratory research has shown that it has greater abrasion resistance and improved de-icing characteristics. RUMAC can also tolerate higher deflections while exhibiting lower permeabilities which decrease oxidation and aging. When distress occurs, it proceeds at a slower rate. Due to these improved characteristics, RUMAC use leads to decreased maintenance costs and lower annual equivalent costs (Van Kirk, 1989). Results of others indicate that RUMAC has a fatigue life two to seven times longer than conventional asphalt concrete (BAS Corp., 1990). If results continue to indicate that RUMAC outperforms conventional asphalt concrete, then more widespread use is expected (Doty, 1988; Van Kirk, 1989).

### Flooring and Surfacing

Crumb rubber is currently being used to manufacture flooring products and to provide long lasting, outdoor athletic surfaces. Because tire rubber is very resilient, all-weather applications are often more durable than conventional surfaces.

Products that have been manufactured include floor mats, anti-fatigue mats, and carpet padding. Floor mats made from crumb rubber can be used in a variety of ways and in special applications such as non-slip mats. Anti-fatigue mats, for workers standing for long periods of time, and carpet padding have been manufactured from crumb rubber. Because rubber has good energy-absorbing properties, it also has been used for noise and vibration control. A Japanese firm has used approximately 70,000 tons of crumb rubber to lay 131 kilometers (about 80 miles) of this padding for railroad construction from 1975-1981 (Kearny, 1990; Pyro Recovery Co. & Huston Trust, 1990).

Running tracks, footpaths and playgrounds can be surfaced with crumb-rubber coatings. For running tracks, the crumb rubber may be between one-eighth inch and one-quarter inch in size. One-quarter inch to one-half inch rubber can be used for footpaths and playgrounds. All applications require that steel and fiber be removed prior to use (SCS Engineers, 1989). Because crumb rubber surfaces are long lasting and more comfortable to exercise on, their popularity is increasing.

### Soil Amendment

Crumb rubber can be added to soil as an amendment. International Soil Systems, a Fort Collins, Colorado-based company, has developed a patent-pending process for conditioning soil. The conditioning process incorporates a site-specific quantity of crumb rubber into the first three to five inches of soil. The proponents claim that the treatment decreases compaction and increases porosity, which results in greater water absorption and oxygen diffusion to grass roots. Sporting fields are one application for the process. Approximately 12,000 waste tires are required to treat one football field. Race tracks and horse trails can also be treated, reducing the concussive force on horses' hooves. Because such a large quantity of tire rubber is required for one treatment, this application has the potential to consume a significant number of tires (Logsdon, 1990).

Soil conditioning experiments have also been conducted in the agriculture industry. One of several plots of a corn field was conditioned at Colorado State University. After an unexpectedly strong storm passed through the area, the only corn plants left standing were in the plot that had been treated. After investigation, it was found that the plot with the conditioned soil had much larger root systems than the untreated plots. At this time the process is not economical for normal agricultural use. Also, the potential exists for metals such as iron and zinc to leach into the soils. The metals could contaminate the crops if they were in a bioassimilative state.

### Composting

Tire chips can be used as a bulking agent for sewage sludge composting. Due to the nature of sludge composting, a bulking agent is required to provide a surface for biodegradation, assist in aeration, and reduce moisture content. Traditionally, wood chips have been used to perform this function. According to Andrew J. Higgins of Rutgers University, New Brunswick, New Jersey, as much as 30 percent of the wood chips are unrecoverable each time they are reused because the wood biodegrades (Higgins, 1987). The final product is also littered with small pieces of wood debris. Tire chips, being very durable, will last indefinitely, are more easily recovered, and are more cost effective than wood chips. One drawback to the use of tire chips, however, is the possibility of metals, particularly iron and zinc, leaching into the compost. According to the EPA, "Recycling the rubber chips reduced the zinc and iron concentrations, but they were still high after five [composting and chip recovery] cycles. However, the levels were not high enough to limit the use of shredded rubber in the composting of sewage sludge" (Higgins, 1987). Due to the fact that the tire chips do not absorb moisture, the biodegradation rate may be slowed, requiring the addition of a quantity of wood chips or sawdust (Higgins, 1987).

### Playground Cover

Tire chips, shredded from only non-steel belted tires, can be used as an alternative to gravel or bark in playgrounds. Rubber Disposal System, Inc., a Steelville, Illinois-based company, shreds waste tires into three-quarter inch chips which can then be spread over various playground surfaces. The Redi-Gro corporation, located in Sacramento, California, markets Safety Soil™, a ground rubber product also designed to be used as an alternative to sand, gravel, or bark used under playground equipment (Redi-Gro Corp., 1991). Aspiration of small rubber particles, however, has been a concern.

### Assessment

Due to high initial costs and limited market development in the rubberized asphalt industry, current tire consumption is small (BAS Corp., 1990). Also, because the crumb rubber must be free of steel and fiber, recycling or disposal of these materials would be required.

According to BAS Corporation, a southern California waste tire processing firm, approximately 40 million tons of asphalt concrete is used annually in California. Twenty million tires (ten pounds of rubber recovered per tire) would be needed to obtain the crumb rubber required to replace ten percent of the conventional asphalt applied in California (BAS Corp., 1990). RUMAC has the potential to use a large percentage of waste tires; however, up to 50 percent of the casing may remain.

It is premature to estimate potential tire rubber use for flooring and surfacing; however, for the near term it is likely to be small due to the size of the market.

If proven economical and environmentally acceptable, the use of soil amendments could use a significant amount of tires (Logsdon, 1990).

Because of the limited amount of sewage sludge currently being composted, the use of tire chips as a bulking agent has limited potential. Also, because chipped tires do not degrade as wood bulking agents do, the chips would not need replacing, limiting potential consumption.

It is unlikely that the use of chipped tires for playground cover will consume a significant amount of waste tires because only non-steel belted tires can be used and also because of the limited number of playgrounds which would use it.

### 2.3.4 Buffings, Reclaiming, and Granulated Rubber

Tire buffings are produced as a by-product of the tire retreading industry. Prior to retreading, the tread remaining on the tire must first be ground off. Tire buffings, the fine particles resulting from this process, are collected and used in a variety of products.

Granulated rubber, or production buffings, is tire rubber that is ground from waste tires specifically for use in a process or product, not as a by-product of retreading. Also, unlike the tire retreading process, the tire casing is not used and requires another means of recycling or disposal.

Granulated rubber can also be produced using the technique of cryogenic processing. Whole or chopped tires are frozen to a brittle state using liquid nitrogen and hammered into pieces ranging in size from one-half inch to about 24 mesh (a fine powder). Magnetic separation is used to remove the steel wire, and air classification is used to separate the fabric fiber from the remaining rubber. Depending on product size requirements and initial granulate size, the rubber may require further size reduction (Kearny, 1990; Sladek, et al., 1989).

BAS Corporation is currently using cryogenic processing technology to produce granulated rubber and promote rubberized asphalt. Tires are split, chopped, frozen with liquid nitrogen, shattered, and classified by granulate size. BAS is currently producing about one ton of granulated rubber per hour of operation. Potential markets for the granulated rubber include RUMAC, rubberized sealcoating, and molded products (Harrington, 1991).

A Michigan-based firm is proposing to site facilities in California which would use cryogenic processing technology to granulate waste tires. The granulated rubber is blended with granulated post-consumer plastic and extruded into pellet form for use in various molded plastic applications (Baker Street Chemical and North American Crumb, 1991).

Reclaimed rubber can be produced from tire buffings or granulated rubber. Traditionally, rubber has been reclaimed by chemical and thermal treatment (devulcanization). This process returns the rubber to a moldable raw material which can then be reused in the manufacture of new products, including tires. Due to the fact that reclaimed rubber cannot be completely devulcanized, problems can occur when blending with virgin material. Also, because reclaimed rubber loses some of its elasticity during devulcanization, it has limited potential uses, especially in products requiring great flexibility such as tires (Sladek, et al., 1989). Barring any technological advances in the rubber reclaiming or tire manufacturing industries, this alternative has little near-term potential to consume a significant number of tires.

### Asphalt-Rubber

Asphalt-Rubber (AR, also known as the wet process) differs from RUMAC in several ways. First, tire buffings or granulated tire rubber, not crumb rubber (as defined), are used. Secondly, unlike RUMAC, AR production involves combining and blending the tire buffings or the granulated rubber with the liquid asphalt, creating a new binder material. Approximately 18 to 26 percent rubber by weight of binder (the binder is eight to ten percent of asphalt concrete) or 1600 tires per mile of two-lane road are used in this process. Additional costs are incurred because of the requirement of specialized equipment for blending and storing the binder. Also, potential problems exist concerning air pollution since melting tire rubber may release volatile organic compounds (VOC) (Kearny, 1990).

Manhole Adjusting Inc., a Monterey Park, California paving firm, uses AR for many applications including highways, surface streets, airport runways, and heavy industry pavements. The company uses tire rubber (heated and blended with liquid asphalt) as a spray-applied membrane (see Rubberized Sealcoating and Roofing, Section 2.3.4) and as a binder for traditional hot mix paving materials (Manhole Adjusting, Inc., 1991). The AR binder is mixed with traditional paving materials in hot mix plants and applied with conventional equipment. Tire rubber from approximately 2,500 tires is required to pave one lane-mile with a two-inch lift. Tire rubber accounts for about 1.6 percent of the final paving mixture.

Most recently (August, 1991), Manhole Adjusting Inc. applied about 53,700 tons of AR concrete on 140 residential streets in Thousand Oaks, California. Approximately 177,000 tires were used to produce the 885 tons of granulated rubber (based upon recovery of ten pounds per tire as granulate [Manhole Adjusting, Inc., 1991]) required for the AR mixture.

According to the Scrap Tire Management Council, "Addition of scrap crumb rubber to asphalt cement is reported to increase the ductility of the wearing surface, improve crack resistance, and reduce cold weather brittleness and hot weather bleeding" (Kearny, 1990). If all new asphalt paving was done with AR concrete, all of the waste tires generated could be used. Current consumption of AR concrete, however, is low. Due to uncertainties from past testing and lack of a consolidated effort to promote AR use, it is unclear if or when it will reach its potential.

### Rubberized Sealcoating and Roofing

One other alternative for the use of tire buffings or granulated tire rubber is sealcoating and roofing. Due to its elasticity, tire rubber has proven effective in reducing crack frequency and severity, thereby lengthening the lifetime of these products.

Sealcoating, with or without the addition of tire rubber, is an important step in road construction. Types of sealcoating include stress absorbing membrane (SAM), stress absorbing membrane interlayer (SAMI), and crack sealant. A SAM is applied to existing asphalt surfaces to help prevent fatigue cracking. A SAMI is used between layers of asphalt to prevent reflective cracking transmitted from base layers to new overlays. Crack sealant, used to fill cracks and joints, can also be made from tire buffings or granulated tire rubber.

AR sealcoating generally reduces road maintenance needs, and pavement lifetime is increased compared to standard sealcoats. Due to the increased performance, annualized costs are competitive compared to conventional sealcoating (Burgess and Niple, and Waste Recovery, Inc., 1987; Sladek, et al., 1989). Manhole Adjusting Inc. uses granulated tire rubber in its membrane applications. The membrane requires the rubber from about 700 tires (20 percent of the total mixture) for one lane-mile (12 feet wide) (Manhole Adjusting, Inc., 1991).

Tire rubber, when combined with a neoprene binder, creates a durable rubberized roofing material. Flex-A-Glas, a Baltimore-based roofing company, has manufactured and tested a rubberized roofing binder, Rubaprene, since 1984. The binder contains rubber particles (10 mesh and 20 mesh) and is pumpable and sprayable. All steel and fiber must be removed from the rubber prior to use. Approximately 300,000 square feet have been applied at a rate of about two pounds of rubber per square yard, with no signs of deterioration (Flex-A-Glas, 1990; Sladek, et al., 1989).

### Surface-Modified Rubber

Surface treatment is a relatively new technology which chemically alters the surface of rubber particles to allow for higher strength bonding with other materials, such as polyurethane. Because rubber cannot be melted and reformed like thermoplastics, this process could enable greater tire rubber usage.

Air Products and Chemicals, Inc., a Pennsylvania-based company, has developed a patented process to chemically modify the surface of the rubber particles. The process involves grinding the tires, removing the steel and fabric, and chemically modifying the remaining rubber by exposure to a reactive gas atmosphere. Peel tests have shown that samples which contain surface-modified rubber have a much stronger rubber-polyurethane bond (Bauman, 1990).

Several other markets for surface-modified waste tire rubber include carpet underlay, non-pneumatic tires, rubber hosing, and sealants and adhesives (Bauman, 1989).

### New and Recycled Rubber Products

Tire buffings, granulated rubber, and reclaimed rubber can be used to produce new and recycled rubber products. Riedel Omni Products, a Portland, Oregon-based firm, manufactures railroad crossings from tire buffings. Approximately 350 pounds of buffings are used for each linear foot of crossing. The projected life of the rubber railroad crossing is 15 years, almost four times as long as conventional asphalt crossings (Kearny, 1990; Sladek, et al., 1989).

Other products made from tire buffings or granulated rubber are automobile belts and hoses, irrigation pipe, wheel chocks, highway sound barriers, and various molded products. Depending on the application, tire rubber may also be used as an additive or extender in rubber, plastic, or rubber and plastic mixtures when structural strength is not necessary.

### Tire Manufacturing

The use of reclaimed rubber has steadily declined due to several factors. These are the increased use of synthetic rubber, the higher standards in the tire manufacturing industry, and the fact that reclaimed rubber can only be partially devulcanized.

Synthetic rubber, a derivative of crude oil, has almost completely replaced the use of reclaimed rubber in the tire manufacturing industry. This is in part due to the low cost of petroleum. Also, because research and development in the reclaimed rubber industry has been neglected due to the declining market, few technological advancements in the field have been made (Sladek, et al., 1989).

The tire manufacturing industry's high standards for tire performance, coupled with the advent of the radial tire, have also contributed to the decline of the rubber reclaiming industry. Because reclaimed rubber, which can only be partially devulcanized, is generally lower quality than virgin rubber, very little (if any) reclaimed rubber can be used in today's radial tires. Tires made with reclaimed rubber show reduced elasticity, compression, stretching ability, and abrasion; hence, tire manufacturers are concerned about safety and liability, and prefer to use virgin rubber almost exclusively. Also, due to the fact that different tire components require different rubber formulas, reclaimed rubber (a blend of many types and grades of rubber) is difficult to use (Sikora, 1986; Sladek, et al., 1989). For these reasons, the tire manufacturing industry has little incentive to consume a significant amount of waste tire rubber.

### Assessment

In past years, both CalTrans and the Federal Highway Administration (FHWA) have considered the use of RUMAC and AR experimental. Due to federal legislation (HR 2590), the Department of Transportation and the EPA have been directed to conduct a study to investigate the use of asphalt pavement containing recycled rubber. CalTrans is supporting further field trials of RUMAC and AR (Congressional Record, 1991; Doty, 1988; Doty, 1991; Van Kirk, 1989).

Although current use is limited, a significant amount of waste tire rubber could be consumed for sealcoating or roofing applications. Because only tire buffings or granulated tire rubber are used, however, the tire casing (or at least the steel and fiber components) may still require recycling or disposal.

Due to the recent emergence of surface-modified rubber and the markets for new recycled rubber products, it is difficult to estimate potential waste tire consumption for these uses.

## 2.4 TIRE-DERIVED-FUEL

Tire-derived-fuel (TDF) has been used to supplement fossil fuels (primarily coal) and biomass fuels (primarily wood wastes) in the United States, Europe, and Japan since the 1970s, and is recognized as a suitable fuel for some combustion process facilities.

This section presents a discussion of the current and potential uses of TDF by the cement industry, pulp and paper facilities, MSW and biomass energy recovery facilities, and other industrial processes. Included are process descriptions, assessments of the feasibility of using tires as fuel in these processes, and estimates of the amount of waste tires that are and potentially may be consumed as fuel supplements for these California industries. The use of tires as fuel in dedicated tire-to-energy facilities, and the process of pyrolyzing tires to recover fuel and materials, are briefly discussed.

### 2.4.1 Cement Manufacturing

#### Introduction

California leads all states with 15 percent of the total national production of Portland cement (U.S. Department of the Interior, 1989). The cement industry is one of the most energy intensive and energy consumptive industries in the state. At full capacity, the 11 existing California cement manufacturing facilities require about 34 trillion BTU of fuel energy per year (0.034 quad/yr), or 2.1 percent of all fossil fuels used by California industries. Approximately 90 percent of the fuel consumed is coal.

The principal steps in manufacturing Portland cement include crushing, grinding, mixing, and roasting minerals, followed by grinding the resulting product called clinker. Three to five percent gypsum is added during the clinker grinding and blending process to create the cement product. About 1.8 tons of minerals are required to produce one ton of cement. The following primary raw materials are required for cement production: limestone or some other calcium carbonate-containing material such as marl, chalk, or crustacean shells; and shale, clay, or diatomaceous earth to provide silica, alumina, and iron oxides. If the shale, clay, and/or diatomaceous earth used does not supply sufficient iron, then iron ore, or some other source of iron such as slag or scrap steel, must be added. Similarly, if other essential components are not present in sufficient quantity in the primary raw materials, other materials must be added to correct these deficiencies.

#### Cement Manufacturing Process

Cement manufacturing involves roasting the properly proportioned mixture of finely ground raw materials in a rotary kiln to a temperature of about 2700 °F to form partially fused nodules called clinker. Nearly two-thirds of the total heat needed for clinker production is required for the decarbonization or calcining reaction (dissociation of carbon dioxide from the calcium carbonate to form calcium oxide or "quicklime"). At higher temperatures the quicklime reacts with silica and alumina to form calcium silicates and aluminates — the primary cement components. The kiln operation is the most important step in producing cement because fuel consumption is a major expense, and strength and other properties of cement depend on the quality of the clinker (U.S. Department of the Interior, 1989).

There are two distinct categories of cement manufacturing processes: the wet process and the dry process. The differences between these processes depend upon the process employed for grinding the raw materials and the resulting moisture content of the kiln feed. For the wet process, the feed is introduced in the form of a slurry, with a water content of 32 to 42 percent, into a long wet-process kiln. The average fuel consumption for the wet process is 4.5 million BTU per ton of clinker produced. For the dry process, the feed is introduced into a shorter kiln and has a moisture content of only about eight percent. At 3.5 to 4.0 million BTU per ton of clinker produced, the dry process consumes less fuel than the wet process. When the dry process is coupled with the more recent energy-saving technology of the suspension preheater and precalciner, fuel is used in a more efficient manner and the production of one ton of clinker consumes only 2.9 to 3.4 million BTU (Canadian Portland Cement Association, 1989; U.S. Department of the Interior, 1989). A suspension preheater and precalciner is a vertical array of cyclones which serve as a cascading feed system to take advantage of the kiln's exhaust heat. Refer to Figure 2-1 for an illustration of a typical cement kiln process.

Another change which was motivated by high energy costs was the conversion from high-grade fuels such as oil and gas, to coal, a lower-grade but more plentiful fuel. Energy costs, however, continue to remain a large fraction of production costs (Kearny, 1990; U.S. Department of the Interior, 1989). This fact has driven the search for suitable, abundant, environmentally-acceptable, and economically-attractive fuel supplements.

### Alternative Fuels

The cement manufacturing process is capable of using a wide variety of fuels. The high temperatures, long residence times of gases, and high turbulence within the kiln and the preheaters and precalciner ensure a greater degree of destruction of organic materials than most other thermal processes.

The Canadian Portland Cement Association (CPCA) states, "Resource recovery through the use of organic (combustible) wastes as supplementary fuel in cement kilns is recognized as one of the best technologies for completely and safely destroying these wastes, while simultaneously recovering their energy value." Additionally, the CPCA asserts that cement kilns can safely destroy many combustible liquid and solid wastes (as demonstrated in California and throughout the nation), and that those wastes possessing high energy content — such as waste oils and solvents, and discarded tires — make excellent kiln fuels (CPCA, 1989).

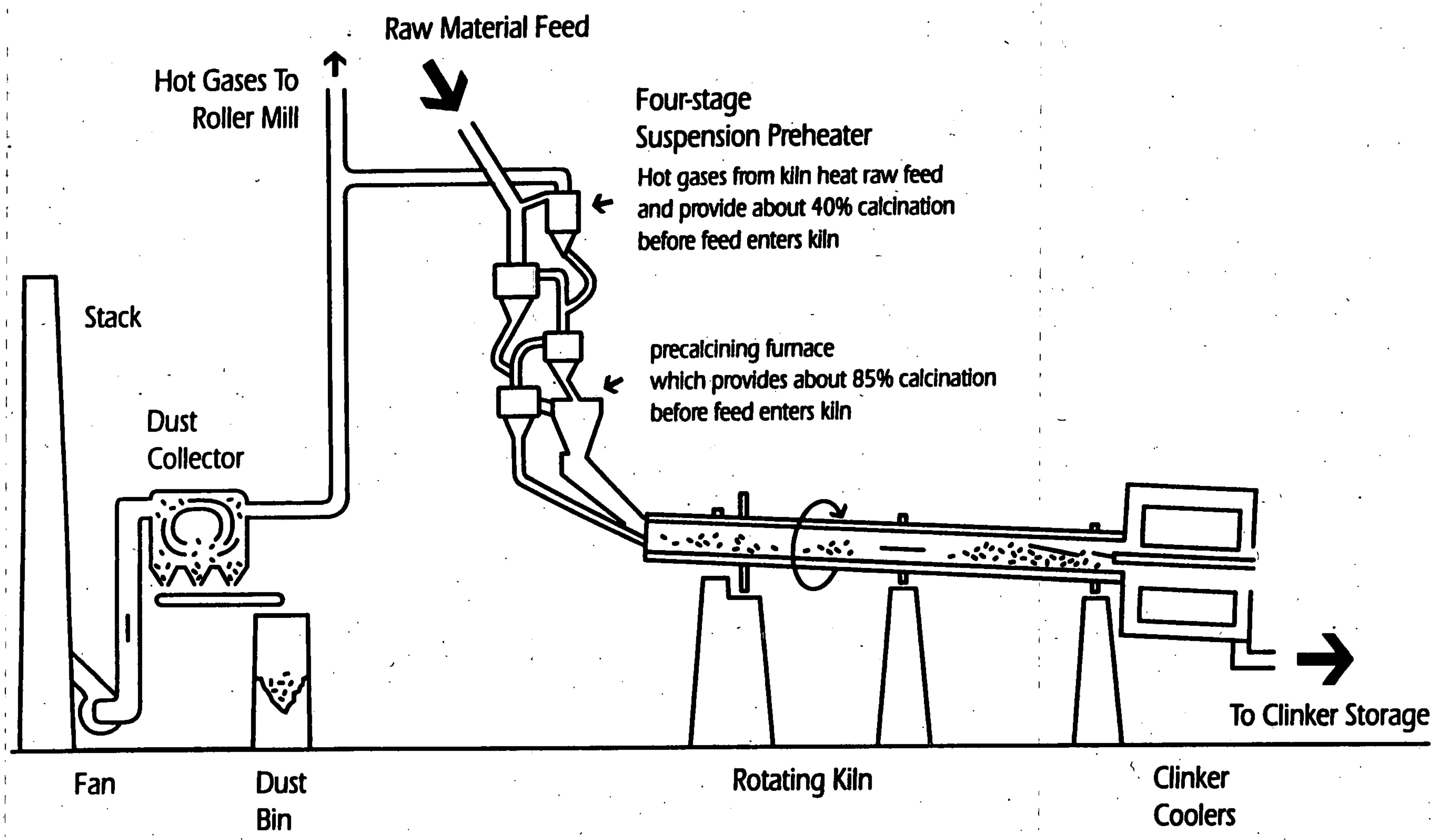
At the Scrap Tire Management and Recycling Opportunities Hearing before the U.S. House of Representatives in April 1990, a Rouse Rubber Industries representative testified (Rouse, 1990) in part, as follows:

> "In general, cement kilns offer the most ideal atmosphere for combustion of these tire fuels due to their design and already existing state of the air pollution control equipment. Also, when tire fuels are combusted in the cement kiln, the ash residue resulting from combustion becomes part of the chemistry of the cement and offers the additional advantage of reducing cement additive cost such as iron oxide which comes from the steel beads and radial wires in tires ... The performance of tire fuels is recognized as an acceptable fuel."

In a September 1990 report (Kearny, 1990) the Scrap Tire Management Council reported the following information regarding the use of scrap tires as fuel in the cement industry:

> "Due to their unusually high operating temperature and long exhaust gas residence times in the burning zone, cement kilns have the capacity to safely use a

**FIGURE 2 - 1**




Kiln system. Preheating, burning, cooling and clinker storage.

wide variety of fuels, including tires or tire-derived-fuel (TDF). Whole tires or TDF are a good auxiliary fuel for coal or oil burning cement kilns because their:

- BTU value is comparable to or higher than typical coal used for making cement.
- Nitrogen, sulfur, and ash content is lower than typical values for coal.
- Steel content provides supplemental iron for the cement.

The high operating temperature in the kiln allows for complete combustion of tires and oxidation of steel beads or belts without adversely affecting kiln operation. Therefore, steel reinforcement does not need to be removed prior to tire use as fuel. In fact, because iron is a basic ingredient in cement, and the temperature in cement kilns is high enough for complete combustion [oxidation] of steel to iron oxide, burning whole tires or TDF with steel content reduces raw material costs for supplemental iron for some kilns."

These comments clearly illustrate the unique attributes associated with the use of tires as a fuel supplement in the cement industry. No ash, slag, or other by-products are generated for which waste disposal is required. The non-combustible materials of the entire waste tire are incorporated into the final product.

In Germany and Japan, 15 to 20 percent of fuel required for the production of cement is substituted by whole tires - usually in kilns with preheaters or precalciners. Modern cement plants are designed and built to include both preheaters and a precalciner. Often, existing kilns are retrofitted with preheaters and a precalciner resulting in a net increase in kiln feedrates and clinker production. These systems also improve fuel efficiency by making use of waste heat from the kiln and by increasing heat transfer to the raw materials, thereby reducing energy costs. According to the EPA, there are currently seven kilns in the United States that consume about six million tires per year. About 50 of the 240 cement kilns (21 percent) operating in the United States are equipped with a precalciner and preheaters (US EPA, 1991).

Tire fuel is most easily fed to the process at or near the precalciner. With some kiln arrangements, TDF may also be introduced with the primary fuel without significant difficulty (Dodds, 1987). With others, minimal capital expenditures are required for tire fuel feed systems, typically less than $500,000. The fuel savings incurred commonly result in payback periods of one year or less. In general, under current air district requirements, upgrading of air pollution control equipment is not necessary for burning tires as a fuel supplement in the cement manufacturing industry. Air emissions issues are discussed in detail in Section 3.3.1.

### Current Status in California

Currently, there is one cement company operating in California which supplements its primary fuel (coal) with tires, and two which have performed test burns and requested modifications to their air permits to do so. Calaveras Cement Company began testing with TDF chips at its Redding facility in 1982. By 1986, about five percent of the total fuel requirement was provided by TDF. Since then, tire-derived-fuel was increased to 14 percent of the total fuel consumed in 1988 and about 20 percent (equivalent to 1.7 million tires) in 1990. Over this time period, substantial fuel savings have been realized due in part to increased fuel efficiencies (equipment and operational modifications), but also due to the use of economically-attractive, waste-derived fuels (Siemering, et al., 1991).

A whole tire feed system has recently been installed at the Calaveras plant. Plant personnel are currently conducting a six-month trial during which whole tires will be the only tire fuel used. The system will feed two and one-half to three tons of whole tires per hour to the precalciner to supply up to 25 percent of the total heat input to the process. If successful, whole tires will continue to be used as fuel instead of tire chips, thereby saving chipping costs.

For the past two years, RMC Lonestar Cement Company has been pursuing a modification of its operating permit for the Davenport plant (near Santa Cruz) to allow the use of TDF as a fuel supplement in its preheater, precalciner kiln. They have completed emissions testing with the use of shredded tires as a fuel supplement. The comparable emissions reported during test burns may allow supplementing 18 to 25 percent of the heat input with tires. Additional testing is planned to evaluate emissions from whole tires. If permitted, this cement plant will consume about 2.2 million tires per year (Malcolm Pirnie, 1991; Portland Cement Association, 1989; Seth, 1991).

Southwestern Cement Company has also been investigating the feasibility of using TDF and whole tires as supplemental fuels for the preheater, precalciner kiln at its Victorville facility. Test burns (using whole tires and chips at 25 percent of the total heat input) and air emissions sampling have been completed. The comparable emissions reported during test burns may allow supplementing 25 percent of the heat input with tires which is equivalent to three million tires annually (Portland Cement Association, 1989; Sheets, 1991). Assuming only 20 percent of the heat input is supplied by TDF, this facility will consume at least 2.3 million tires annually.

Tire-derived-fuel may also be used as a supplemental fuel in cement manufacturing facilities which use long dry- or wet-process kilns. These kilns do not have preheaters or precalciners, but instead, contain large steel chains inside the feed end which extend for about ten percent of the length of the kiln. These act to break up large masses of clumped feed material and to enhance heat transfer. This zone of the kiln is comparatively cool (800 °F to 1000 °F), and as such, is the preheating section of the process. This is not a practical location to feed a fuel derived from rubber tires, because they tend to get hung up where the temperature is too low to complete combustion, causing increased carbon monoxide and organic air emissions.

To use tires as fuel in long kilns, they must be injected into the calcining zone where the temperature is sufficiently high to provide complete combustion (or about 2000 °F as in a precalciner), and where the fuel needs are significant. Because the kiln rotates, mid-kiln injection of tire fuels requires specialized feed mechanisms which include double air locks and loading ports positioned through the kiln wall. Following modification of the equipment and test burns conducted to optimize the process, long kilns may be suitable for co-firing 10 to 15 percent tire-derived-fuel (Hansen, 1990; Sheets, 1991).

## Assessment

Table 2-1 provides a summary of present and potential capacities for the cement industry to consume waste tires by using them as supplemental fuel. There are currently 19 cement kilns operating in California: 6 preheater and precalciner-equipped kilns, and 13 long dry-process kilns. In addition, plant start-up commenced in November, 1991, at Calaveras Cement Company's Tehachapi facility, which has one new preheater and precalciner kiln. Current and potential waste tire consumption by the California cement industry are summarized as follows:

- Assuming Calaveras Cement Company's Redding facility continues to consume about 1.7 million tires per year, and if RMC Lonestar and Southwestern receive modified permits to operate using TDF at expected rates, a total of 6.2 million tires would be consumed annually.

- If all seven facilities with preheater/precalciner kilns (the design from which most tire-fired kiln experience has been obtained and documented) substituted 20 percent of their fuel with tires (on a heat input basis), 18 million tires could be consumed annually.

- If all preheater/precalciner kilns were supplemented with 20 percent tires, and all 13 long kilns were supplemented with

**TABLE 2 - 1**

CURRENT AND POTENTIAL TIRE FUEL CONSUMPTION FOR THE CALIFORNIA CEMENT INDUSTRY

| Facility | No. of Kilns | Process[1] | Fuel[2] | Reported Clinker Production ($10^3$ tons/yr) | Current TDF Use ($10^6$ tires per yr) | 20% TDF for PH/PC Kilns Only ($10^6$ tires per yr) | 20% TDF for PH/PC & 15% for Long Kilns ($10^6$ tires per yr) |
|---|---|---|---|---|---|---|---|
| Calaveras Cement Redding | 1 | PH/PC | C, T (G) | 651 | 1.7 | 1.7 | 1.7 |
| Calaveras Cement Tehachapi[3] | 1 | PH/PC | C | 750 | - | 1.6 | 1.6 |
| California Portland Cement (Onada) Colton | 2 | Long Dry | C, Ck (O, G) | 727 | - | - | 1.6 |
| California Portland Cement (Onada) Mojave | 1 | PH/PC | C (O, G) | 1039 | - | 2.5 | 2.5 |
| Riverside Cement (Gifford-Hill) Oro Grande | 7 | Long Dry | C (G) | 1148 | - | - | 2.3 |
| Riverside Cement (Gifford-Hill) Riverside | 2 | Long Dry | C, Ck (G) | (132 White) | - | - | 0.2 |
| Kaiser Cement Permanente | 1 | PH/PC | C, Ck (G) | 1530 | - | 3.7 | 3.7 |
| Mitsubishi Cement Lucerne Valley | 1 | PH/PC | C (O, G) | 1600 | - | 4.0 | 4.0 |
| National Cement Lebec | 1 | Long Dry | Ck (W) | 650 | - | - | 1.3 |
| RMC Lonestar Davenport | 1 | PH/PC | C, T | 800 | - | 2.2 | 2.2 |
| Southwestern Cement Victorville | 1 | Long Dry | C (O, G) | 620 | - | - | 1.3 |
| | 1 | PH/PC | C, T (O, G) | 930 | - | 2.3 | 2.3 |
| **Totals** | 20 | 13 Long Dry Process<br>7 Preheat/Precalcine | | 10,445 (132 White) | 1.7 | 18.0 | 24.7 |

Source: Portland Cement Association Plant Information Summary, 1989; CIWMB files.

1 "PH/PC" = kiln is equipped with feed cascade preheaters and a precalciner; "Long Dry" = long dry process kiln with no PH/PC.
2 Fuel codes: C = Coal, T = Tires, G = Natural Gas, Ck = Petroleum Coke, O = Oil, W = Waste, ( ) = Alternate or start-up fuel.
3 Plant start-up has commenced as of November, 1991.

15 percent tires (currently assumed to be the maximum tire fuel usage for these types of kilns), nearly 25 million tires could be consumed annually.

### 2.4.2 Pulp and Paper Industry

The pulp and paper industry is also very energy intensive. Electrical energy is required to operate plant equipment, and enormous quantities of steam are required for heating and drying processes.

#### Process Description

Kraft or Sulfate pulping is the predominant process by which wood pulp is currently made. The raw material for pulp is fibrous cellulose which is derived from wood and recycled from waste paper.

Kraft pulp production includes the following major processes (Austin, 1984):

- Wood chips are steamed to recover volatile materials (turpentine and non-condensible gases), and then cooked with an alkaline solution of chemicals called "white liquor" in a digester. In this process, about half of the wood, composed primarily of lignin, is dissolved to release the cellulose fibers.

- The fibers are removed, and the spent cooking liquid, or "black liquor," is concentrated by evaporation and burned to recover and reuse the inorganic chemicals, and to recover energy from the organic (lignin) portion.

- The washed pulp is screened to remove knots, unreacted chips, slivers, trash, etc., then sent to thickeners and filters.

- The pulp is bleached, washed and re-thickened in preparation for making it into "laps" which are coarse sheets of partially dried pulp dry enough to bundle, store, and ship. Laps are the primary raw material for making paper products. For integrated pulp and paper mills, the finished pulp slurry may be fed directly to the paper-making process.

Historically, pulp mills have been largely self-sufficient in meeting their steam, heat, and electrical energy demands. Wood wastes generated by the cutting, debarking, and chipping processes, as well as organic wastes from black liquor recovery, pulp washing, and wastewater sludge, have been combusted in hogged-fuel or combination-fuel boilers to produce process steam, heat, and electrical energy (Malcolm Pirnie, 1991).

The advantage of a paper mill which is integrated with a pulp mill is that it can obtain a substantial portion of its energy demand from the surplus heat of the pulping operation; whereas, a paper mill alone is forced to produce or to purchase the majority of its energy needs or fuel (OECD, 1985).

#### Alternative Fuels

Due to the high moisture content (40 to 55 percent) and low heating value (4,000 to 5,500 BTU/lb) associated with typical composite wood wastes, higher value fossil fuels such as coal or fuel oil are often required to stabilize operation of combination-fuel boilers. The high heating value and low moisture content of tires make them a suitable fuel to co-fire with wood wastes (Jones, et al., 1990). Stoker-grate boilers are generally used to burn solid wood wastes and partially dewatered biological sludges. When shredded or chipped tires containing most of their steel cord and bead wires are used as a supplemental fuel, they often become caught in the boiler fuel feed system and/or on the stoker-grate. Dewired TDF (heating value approximately 15,000 to 16,000 BTU/lb) is, therefore, usually required to avoid handling problems in existing systems (Gjesvold, 1991; Jones, 1991; Kearny, 1990; Nepote et al., 1991).

#### Experience with TDF

According to plant management at Inland-Rome's mill in Rome, Georgia (Jones, et al., 1990; Jones, 1991), the use of TDF as a supplemental fuel with wood waste and biological sludge in a combination-fuel stoker-grate boiler has the following advantages:

- Promotes drying and increases combustion efficiency of companion fuels containing substantial quantities of moisture.
- Enables disposal of biological sludge in conjunction with wood waste without necessitating the purchase of fossil fuels such as pulverized coal.
- Has fewer environmental disadvantages when compared with coal.
- Has a cost advantage when compared with other purchased fuel supplements such as coal or oil.

Champion International's Bucksport, Maine, mill has been burning TDF full-time since November 15, 1990. For a period of about three years prior to this, the feasibility of using TDF as a fuel supplement was investigated, test burns were conducted, and permit changes were made with assistance from Maine's Department of Environmental Protection.

About three tons per hour (ten percent of total heat input) of dewired TDF is burned in a traveling-grate combination-fuel boiler rated at 500,000 lb/hr steam production. The boiler was designed to burn coal, petroleum coke, wood wastes, biomass, number 6 fuel oil, and non-Kraft process wastewater sludge. The boiler is now permitted to burn up to three and one-half tons per hour of TDF with a heating value of 15,500 BTU/lb.

The facility's air permit stipulates that the TDF be 98 percent free of bead wire and 75 percent free of belt wire. Particulate matter emissions are controlled by multiclones and an electrostatic precipitator (ESP). Tire-derived-fuel is fed to the boiler via the existing biomass pneumatic conveyer feed system. This process consumes approximately two and one-half million tires per year. Air emissions issues for this facility and for Port Townsend Paper Company in Washington are discussed in Section 3.3.1 (Harrison, 1991; Woodman Engineering Inc., 1990).

Some pulp and paper mill operators in Oregon have been using TDF as a fuel supplement in their hogged-fuel boilers for several years. Recently, they have expressed interest in expanding the use of TDF; however, source testing for air pollutant emissions is required as a first step toward obtaining revised permits for any significant fuel change (Mueller-Crispin).

### Current Status in California

Particulate emissions generated by fuel combustion are generally proportional to the ash content of the fuel and are significant for wood, coal, and tire combustion (Edde, 1984). As a consequence, particulate emission control devices are required, and in California, with its stringent air emissions standards, these controls must be especially efficient. Most pulp and paper mills have multiclones, the traditional technology for particulate control of wood-burning boilers, and have not been retrofitted with costly, more efficient ESPs, baghouses, or scrubbers.

Rather than adding adequate air pollution control technology to their processes, most California mills avoid the environmental and economic problems associated with burning wood wastes by simply selling them as fuel to local biomass combustion facilities (Iwanick, 1991; Matteson, 1991). Because many of these facilities were built recently in comparison with established pulp and paper mills, they have the necessary control devices in place to ensure compliance with current permitted discharge limits. Refer to Section 2.4.3 for more information on biomass facilities.

Only one pulp and paper mill in California, Louisiana-Pacific in Samoa, still burns wood wastes in its combination-fuel, stoker-grate power boilers. Particulate emissions are controlled by multiclones followed by recently installed ESPs. The auxiliary fuel is natural gas.

### Assessment

Based on preliminary tests, the Samoa plant may be able to consume up to two percent TDF (by weight) as a supplemental fuel (Nepote et al., 1991), or nearly one million tires per year with their present fuel feed and stoker-grate systems, provided that sulfur dioxide, particulate matter, and other air pollutant emissions do not exceed permit limits. Further testing with TDF as a fuel supplement is required to quantify emissions and to determine the permissible process operating range, taking into account environmental, economic, and performance issues.

### 2.4.3 MSW and Biomass Waste-to-Energy Facilities

#### Introduction

There are 60 combustion facilities in California which burn wood wastes, agricultural wastes, and MSW to produce steam and electricity (cogeneration), electricity only, steam only, or hot water. Three of these facilities — the Southeast Resource Recovery Facility, the Commerce Refuse-to-Energy Facility, and the Stanislaus Resource Recovery Facility — burn over 700,000 tons (as received) of municipal solid wastes annually to generate electricity. The biomass facilities consume in excess of seven million tons per year of wood waste (including lumber mill and urban wood wastes), agricultural waste, and animal waste. Lumber mill waste is used as fuel more than any other biomass material (NEOS Corp., 1991; CIWMB files).

Municipal solid waste and biomass fuels typically have substantial moisture contents (5 to 50 percent by weight), and low to moderate heating values (3,500 to 9,000 BTU/lb) when compared to fossil fuels and tires. As for any combustion process, biomass and MSW combustion facilities are designed to burn fuel having a specific (and often quite narrow) range of characteristics, particularly those related to heat release, moisture content, and ash (inorganic) content. Most of these combustion plants, therefore, do not tolerate fuels with properties which are incompatible with operational design, especially if the fuel is to be used in large amounts or in a form or manner that results in fluctuating performance.

Operational problems for any combustion facility can result if fuel characteristics are incompatible with existing fuel handling and feed system designs. Fuel size, shape, and handling characteristics must be considered. Exposed steel wire in TDF can get caught in some of these systems. Where problems occur, either fuel specifications must be revised (such as switching to dewired TDF), existing fuel handling and feed systems must be altered, or new systems must be designed and installed.

#### Process Description

The stoker-grate and fluidized-bed (including bubbling and circulating bed designs) boilers are the dominant technologies in California's biomass plants and are most suited to firing solid fuels including many types of biomass and TDF. Brief descriptions of these processes are presented in Section 2.4.4. In addition to fuel handling and feed problems, some of these types of units have had other problems with the steel wire present in TDF. For stoker-grate boilers, wire has been known to slag or get caught in the grates. For fluidized-bed boilers, wire can get hung-up in the ash removal system. Nationally, successful test burns have been conducted with TDF for both types of processes.

#### Current Status in California

Only limited testing with TDF has been conducted in California, and the testing has not always been well documented. According to the CARB, one traveling-grate boiler experienced slagging which was attributed to the steel in the tires. Also, tests have shown increased nitrogen and sulfur oxides emissions, and significant increases in particulate emissions. No specific information regarding boiler design, operation, or air pollution controls has been received; however, it is known that many biomass facilities have historically had only minimal air pollution controls for SOx and particulates. Multi-cyclones (sets of cyclonic air separators arranged in series) were often the only equipment installed for the purpose of controlling particulate matter emissions. Many newer, modern facilities now have high-efficiency baghouses or ESPs to control particulate emissions, and several have both NOx and SOx emissions control systems.

Energy Products of Idaho, Inc. (EPI) has designed and built five fluidized-bed biomass combustion facilities in California. An EPI representative has suggested that, based on the heat release characteristics of tire fuels, these units may be able to use significant amounts of dewired TDF chips as fuel (Murphy, 1991).

There are currently eight biomass combustion facilities in California that are known to have controls to limit NOx, SOx, and particulate matter emissions. Six of these are of the fluidized-bed, bubbling-bed, or circulating-bed design. All use ammonia injection to control NOx emissions, limestone or bicarbonate as some fraction of the feed to limit SOx emissions, and baghouses or ESPs to control particulate emissions. The other two facilities are stoker-grate boilers equipped with ammonia injection, a dry scrubber or lime injection to control SOx emissions, and baghouses or ESPs to control particulate emissions. One of these facilities uses a state-of-the-art vibrating-hydrograte fuel system design. Water tubes are in place under the grate to keep it relatively cool, which allows a thinner layer of fuel to be run on the grate than on conventional grates. This promotes greater combustion efficiency and reduced carbon monoxide emissions, and reduces slagging. One facility engineer expressed interest in testing up to one and one-half tons per hour of TDF (a potential consumption of about one million tires annually), and if results are favorable, to use TDF as a fuel supplement on an ongoing, or as-needed basis (Jennings, 1991).

There are also another nine fluidized-bed facilities that have high-efficiency particulate matter control (baghouses or ESPs), but do not have both SOx and NOx control in place. The control of these pollutants, however, often requires only boiler modifications such as ammonia injection for NOx, and the addition of limestone to the feed for SOx. Such modifications may be significant in some cases. For stoker-grate boilers, however, control of SOx is accomplished by a downstream air pollution control device such as a dry scrubber. Flue gas treatment requires large capital expenditure, and has high associated operating costs compared to control within a fluidized-bed boiler.

The three existing WTE facilities are equipped to control sulfur dioxide emissions (within a design range); therefore, they can accommodate some variations in fuel sulfur content. These facilities are not currently permitted to specifically burn tire fuel and will not accept a load full of tires. Mixing waste tires with MSW at a rate of 5 percent by weight, or 10 to 15 percent by total heat input, however, may improve combustion efficiencies and process performance — especially when mixed with high-moisture/low-heating value wastes. Existing air pollution control equipment may be sufficient to control emissions which result from co-firing small quantities of tire fuel at these facilities.

#### Assessment

Performance and air pollutant emissions tests will need to be conducted prior to using tires as a fuel supplement at any facility. Results of these tests would be used to determine whether or not TDF is a compatible fuel for these facilities, with consideration for process performance and economics, and environmental impacts. The first group of eight biomass facilities may have sufficient air pollution controls to allow supplementing small amounts of tire fuel and, as a result, may have the greatest potential to use tires. Approximately one million dry tons of biomass fuel is consumed annually by these facilities. By supplementing five weight percent TDF for primary fuel, nearly six million light-duty tires would be consumed annually. The second group of nine facilities consumes in excess of one million tons of biomass fuel annually. If any necessary boiler modifications were made and the existing particulate controls prove to be adequate, five weight percent TDF may be used as supplemental fuel, and nearly seven million tires could be consumed annually. The three MSW combustion facilities have the potential to consume in excess of four million tires per year (at five weight percent primary fuel replacement) if performance and air pollutant emissions tests are positive.

### 2.4.4 Other Industrial Processes

Existing industrial and utility combustion processes that are considered potential candidates for using waste tires as a primary or supplemental fuel must be designed to burn solid fuels which have properties that are similar to those of tires; otherwise, significant capital expenditures may be required for redesign and equipment retrofits. In addition, consideration must be given to combustor operation, as well as to ancillary equipment design, including fuel feed, ash collection, and environmental control devices. TDF properties including heat release rate, moisture content, sulfur content, and air emissions generated from combustion are most similar to the properties of bituminous coal. Tire-derived fuels have, therefore, been most easily combusted in processes which were designed to burn coal. Historically, most coal combustion processes have been of a stoker-grate boiler design which burns lumps of coal that are supported on a grate. This design has been one of the most adaptable to burning tire-derived chips (McGowin, 1991; Waste Recovery, Inc., 1985).

Many utility boilers in the mid-west and eastern United States are designed to burn pulverized coal in suspension using a burner specifically designed for this purpose (similar in operating principle to a gas-fired burner). It is unlikely that crumbed rubber, such as that produced cryogenically, would be a suitable fuel (on a technical and economic basis) for a pulverized-coal boiler. A combination stoker-grate/pulverized-coal boiler, or a pulverized-coal burner retrofitted with a grate, however, would be more feasible.

California industries (with the exception of the cement industry) and utilities have not used tires as a fuel supplement because their power and steam-producing processes burn oil or gas. The availability and quality of coal in California has historically been limited in comparison with the mid-west and eastern portions of the United States; therefore, coal has not been the fuel of choice. In addition, strict California air emissions limitations have prevented the widespread use of coal as a fuel due to inadequate or costly air pollution control technologies. Boilers and combustion turbines in California are designed to burn relatively clean-burning natural gas and medium to high-grade fuel oils (with adequate air pollution controls). Currently, existing California industries (with the exception of the cement industry) and utilities provide limited potential to burn tire-derived fuel.

Nationally, most industrial facilities that have used tire fuels have been stoker-grate-fired boilers and have supplemented coal, wood, and sludge wastes with 2 to 20 percent as TDF. Utility experience with waste tires is in its early stages of development. There has been some use of tires in traveling-grate stokers, and most recently in cyclone-fired units. Cyclone boilers offer one of the best available methods of recovering energy from tires, especially for facilities burning lower-grade coals such as lignite. Co-firing TDF with lignite has provided improved flame stabilization and combustion efficiency. Also, there are many of these types of utility boilers nationwide (Koziar, 1991; Schreurs, 1991; Stopek, 1991).

Circulating Fluidized-Bed (CFB) combustion systems have become popular since the late 1970s, and with increasing emphasis on controlling air emissions, this technology is likely to have a stable future in the boiler market. CFB systems can be more cost effective than traditional stoker-grate and pulverized-coal fired units when emission control is considered.

CFB combustion systems inherently handle a wider range of fuels than traditional boilers, and have advantages in the combustion of low-grade fuels, such as coal waste and biomass, and waste fuels such as tires and MSW. CFB boilers often demonstrate superior carbon burn-out efficiency. Units designed with long furnace gas residence times, overfire or secondary air systems, and fly ash reinjection are better able to completely combust tire fuel than units not having these features. In addition, control of sulfur dioxide emissions is accomplished in the boiler itself when the fuel is combusted with an acid gas absorption media such as limestone. This feature allows substantial savings in capital investment and operation and maintenance costs. Tires have been successfully fired in fluidized-bed boilers. The air quality impacts of burning tires in fluidized-bed boilers, however, have not been evaluated in California (Dry, et al., 1990; Howe, 1991; Phalen, 1991; Pope, 1990).

## 2.4.5 Dedicated Tire-to-Energy Facilities

Whole or shredded tires may be directly combusted at dedicated tire-to-energy facilities to produce electricity. Oxford Energy Company designed, built, and has been operating the Modesto Energy Project in Westley, California, since 1987. This facility incinerates whole tires in a stoker-grate boiler while controlling nitrogen oxides, sulfur dioxide, and particulate emissions with Thermal DeNOx, a limestone slurry spray scrubber, and a baghouse, respectively. The heat energy released by the combustion process is used to produce high-pressure steam which drives a turbine to generate about 14 MW of electrical power — enough to supply the electrical needs of 14,000 homes. This facility consumes four and one-half to five million tires annually.

Oxford Energy has also recently completed construction of a tire-to-energy facility in Sterling, Connecticut, and is planning several others throughout the United States, including one in Moapa, Nevada (see Section 2.1.3). A primary consideration when siting these facilities is the availability of an ample and guaranteed supply of tires. No further plans are known to exist for more facilities in California.

## 2.4.6 Pyrolysis

Pyrolysis, also known as gasification, liquefaction, or destructive-distillation is defined as thermal degradation in the absence of oxygen. When rubber is pyrolyzed it decomposes into three recoverable fractions: carbon black (with steel, fiber, and ash), oil, and gas. Carbon black is one of the main raw materials (25 to 31 percent by weight) for tire manufacturing. The oil distilled from the process can be used as a low-grade fuel oil, while the gas produced is usually burned to provide the process energy requirements. Process conditions are dependent on unit design and operation, and can be varied to yield different quantities and qualities of carbon black, oil, and gas.

The tire manufacturing industry is the largest consumer of recycled carbon black. Due to the high standards of today's tires and the fact that different grades of carbon black are used in different components of the tires, the mixed grade carbon black produced by tire pyrolysis cannot be used in most tire manufacturing applications. Other potential existing markets for carbon black include printing inks and pigments, and activated carbon used as an adsorption media for control of some organic compounds (Sladek, et al., 1989; Waste Recovery, Inc., 1985).

Conrad Industries, Inc. of Centralia, Washington, has been operating a tire pyrolyzer since 1986. The process is capable of converting one ton of tire chips per hour (equivalent to about 800,000 tires annually) into 600 pounds of carbon black, 90 gallons of oil, and three million BTU (30 therms) of gas. Conrad is currently in the process of marketing their process, and is considering auto shredder fluff and mixed plastics as other potential feedstocks. According to a company representative, their carbon product may be suitable for adsorption of some organic compounds such as pesticides and oils from contaminated soil and water.

RMAC Corporation of Troutdale, Oregon, received a grant from the Oregon Department of Environmental Quality to build and operate a tire pyrolyzer. Testing and modifications are nearly complete, and the unit should be operating full-time by December, 1991. The system will pyrolyze three to five tons per hour (about 100 tons per day, or 3.3 million tires per year) of two-inch dewired tire-chips prepared by three shredders. The pyrolytic oil is equivalent to a low-grade fuel oil, while the gas which has a low BTU content has a limited market. The gas will be used to provide process heat, and also to produce steam for a process that strips organic solvent-contaminated soil.

Currently, no known tire pyrolysis processes are operating within California. Tire pyrolysis is not yet commercialized in the United States. Major reasons for this include the high capital costs associated with process equipment, lack of markets, and relative low value of the products, especially carbon black.

# Impediments to the Increased Use of Waste Tires

Factors which impede the use of waste tires include energy requirements for transportation and processing; product quality requirements; potential environmental impacts; economics; and siting, regulatory, and permitting requirements.

The high cost to process or use waste tire rubber and limited revenues from the sale of products are economic barriers to waste tire use. These costs will be offset by collection fees and by avoiding the landfill disposal fee. The profit from an operation must provide a sufficient rate of return on capital investment to make the operation economically viable.

Alternate uses of waste tires, in general, will be impeded if environmental impacts, including air emissions, water contamination, and wastes and by-products are significant and are not easily handled. Historically, the lack of emissions data has led to delays in siting and permitting facilities using tires. Much of the discussions on air emissions and siting and permitting issues were provided by the CARB in Sections 3.3.1 and 3.5.

## 3.1 ENERGY REQUIREMENTS

Major barriers which impede the use of waste tires are the large energy requirements associated with transporting, shredding and chipping, and other types of processing and use.

### 3.1.1 Transportation

Used tires are discarded over a widely dispersed area. Collecting and hauling them to the point of use or disposal requires substantial amounts of energy. An average gallon of diesel fuel contains approximately 148,000 BTU of energy. Assuming a conservative fuel mileage of six miles per gallon for a tractor trailer (Motor Vehicle Manufacturers Assoc., 1990), the energy consumed for every mile traveled is equivalent to 24,700 BTU. Assuming that an average light-duty waste tire weighs 18 pounds and the energy content is approximately 14,000 BTU/lb, the total energy content per tire is 252,000 BTU. A tractor trailer, therefore, consumes the energy equivalent of one tire to travel approximately ten miles.

Waste tires may be transported whole or shredded. Because shredded tires occupy between 25 and 50 percent of the volume of whole tires, a greater amount of tire material may be transported using about the same amount of fuel. In California, the maximum legal tractor trailer weight (cargo included) is 80,000 pounds. When whole tires are hauled, trailer volume is the limiting factor to the load size. The maximum number of whole tires that can be transported in a tractor trailer is about 1,700 (approximately 15 tons). When shredded tires are hauled, however, the trailer is loaded to full legal weight capacity (the limiting factor when shredded tires are transported). The maximum amount of tires that can be hauled in shredded form is about 24 tons which is equivalent to approximately 2,600 tires (Bungay, 1991; Lockington, 1991). Three tractor trailers are required to haul the same quantity of whole tires as two tractor trailers hauling shredded tires.

Whole waste tires may also be baled to reduce their volume and to allow for easier handling prior to transportation. S.F. Royster Tire Disposal (Tracy, California) is currently modifying a horizontal baler which hydraulically reduces 18 tires placed sidewall-to-sidewall (11 feet in length) to a 2.5 foot long bale. Each bale weighs approximately 350 pounds to 400 pounds, and will be sold for between $2.50 and $3.00 each ($.14 to $.17 per tire). Baled tires are relatively easy to haul by truck or by rail because of the compaction achieved. Due to the volume reduction (about 75 percent), weight capacity is the limiting factor when transporting baled tires by truck (Royster, 1991).

The energy required to transport tires, whether whole or shredded, is approximately 24,700 BTU/mile, as described above. The energy requirement for hauling shredded tires is about 9.5 BTU/mile/tire (24,700 BTU/mile/2,600 tires), and for whole tires is about 14.5 BTU/mile/tire (24,700 BTU/mile/1700 tires).

### 3.1.2 Processing

Because tires are designed for toughness and durability, the shredding, chipping, and grinding processes require substantial amounts of energy. One of many tire processors, Huston Enterprises, Inc., a Sacramento-based company, markets tire shredders that produce three and one-half to four-inch strips. This material is a coarse shred suitable for landfilling. The shredder is powered by a 365 hp engine, and is cap-able of processing about 2,000 light-duty tires per hour (Huston Enterprises, Inc., 1990). Based on these figures, the energy requirement to shred tires is approximately 500 BTU/tire. Based on optimal energy consumption, tires should be transported whole if the distance is less than about 100 miles, and transported shredded if the distance is over 100 miles (14.5 BTU/mile/tire * 100 miles = 9.5 BTU/mile/tire * 100 miles + 500 BTU/tire). Because of the handling requirements for whole tires, the realistic mileage breakpoint probably exceeds 100 miles. If the tires will be shredded for the end use, however, then they should be shredded prior to transporting because of the handling difficulties of whole tires.

As the size specification of the shred or chip is decreased, the energy requirement increases substantially. The energy requirements can be compared to the energy equivalent of a tire, about 250,000 BTU. The values for several size specifications are shown below (Columbus McKinnon Corp., 1990; Sladek, et al., 1989).

| | |
|---|---|
| • Coarse Shred | 500 BTU/tire |
| • 2x2 inch Chip | 2500 BTU/tire |
| • 1x1 inch Chip | 15,000 BTU/tire |
| • Crumb Rubber (1/4-1/2 inch) | 35,000-50,000 BTU/tire |
| • Cryogenic Granulate | >100,000 BTU/tire |

## 3.2 QUALITY REQUIREMENTS

Another barrier that impedes tire rubber use is the perception of poor recycled product quality. Both the reclaiming and the retreading industries have attempted to overcome past reputations of inferior product quality. Retreading sales have continued to decline, and reclaimed rubber has not been successful in competing with virgin rubber. Due in part to the lack of consistently positive test results (see Sections 2.3.3 and 2.3.4), the use of RUMAC and AR has not become significant since its introduction over 20 years ago.

Retreaded tires have had a public image of poor quality and substandard safety as a consequence of inferior technology and quality control in the past. Statistics show, however, that contrary to public perception, modern retreaded tires are comparable to new tires in quality and safety (TRIB, 1990).

Sales of retreaded passenger vehicle tires are also declining due in part to the types of tires currently in demand. Many consumers purchase tires designed for appearance and improved performance characteristics, which are not always associated with retreaded tires. Retreaded tires, therefore, will continue to have a limited market. Furthermore, since tire technology is continuously evolving, tires retreaded from past models are not compatible with many modern vehicles.

Reclaimed rubber cannot be completely devulcanized. This impairs the ability to blend and bond it with virgin rubber. Also, reclaimed rubber has lower elastic properties. Because of these factors, little reclaimed rubber is used by the tire manufacturing industry where about 70 percent of all the virgin rubber produced is consumed. Until the quality can be improved, the majority of the reclaimed rubber produced will be used as a filler material or by industries with lower quality requirements than tire manufacturers (Sladek, et al., 1989). Because overall demand will be low without the tire manufacturing market, the use of reclaimed rubber is not likely to account for a significant number of tires.

The addition of tire rubber to asphalt binders or asphalt concrete may impede or prevent these asphalt pavements from being recycled. Asphalt pavement is recycled by being ground for use as an aggregate in new asphalt concrete. The effects of tire rubber in recycled asphalt concrete is a concern of both the Federal Highway Administration and CalTrans (Doty, 1991).

## 3.3 POTENTIAL ENVIRONMENTAL IMPACTS

Potential impacts on public health and the environment are impediments to the uses of waste tires. The potential impacts include air emissions from the combustion of tire rubber, surface and ground water contamination from harmful constituents leached from tire rubber, and wastes and by-products from combustion or processing. Much of the following discussion on air emissions was provided by the CARB.

### 3.3.1 Air Pollutant Emissions

The emissions from substituting tires for a portion of the fuel burned in new or existing facilities are likely to vary depending on the type and design of facility, type of primary fuel being burned, percent of primary fuel being replaced with tires, air pollution control equipment, and other factors (see Malcolm Pirnie, 1991). In cement kilns, where the fuel is burned in contact with the cement feedstock (lime, silica, alumina, and iron), emissions are also affected by the feedstock components.

Burning tires can result in emissions of criteria pollutants such as carbon monoxide (CO), nitrogen and sulfur oxides ($NO_x$ and $SO_x$), particulate matter (PM), hydrocarbons (HC); and noncriteria pollutants such as arsenic, cadmium, chromium, lead, zinc, dioxins and furans, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), benzene, and other organic compounds. These pollutants are also emitted from combustion of other fuels, such as coal, the primary fuel for cement kilns. The quantity of emissions from burning tires as a supplemental fuel, and the relative emissions compared to operating the facility without this supplemental fuel, can only be determined by emissions testing. Comparing the composition of fuels, however, can give an indication of likely relative emissions. Refer to Appendix A for a comparison of the compositions of tires, western coal, MSW and RDF, and biomass.

The heating value of tires is comparable to that of coal and two to three times that of MSW, RDF, or biomass. Tires typically have higher sulfur concentrations than these other fuels, with the exception of many mid-western and eastern coals. Chlorine, a precursor to hydrogen chloride (HCl) and dioxin emissions, is higher in tires than in western coal, but lower than in MSW or RDF. Of the metals found in MSW and RDF, all metals except zinc appear to be in lower concentrations in tires. Tires and western coal are more similar in metal content, although zinc and lead are substantially higher in tires, and some other metals such as arsenic are somewhat lower in tires. The effect on emissions of these differences in fuel composition can be moderated by the volatility of the metal, percent of each type of fuel burned, the pollution control equipment, facility design and other factors, and can only be confirmed by emissions testing.

#### Cement Kilns

Dry process kilns built since 1979 are commonly of the preheating and precalcining design. This type of system allows the sensible heat in the kiln exhaust gases to dry, and to partially calcine, the raw material before it enters the kiln. In this type of system, fuel is fired in both the precalciner as well as the kiln. Because heat transfer in a preheater is much more efficient than in the preheating zone of a kiln, preheating and precalcining type systems are also much more energy efficient.

Particulate matter is the primary emission from the manufacture of Portland cement. Emissions also include the normal products of combustion of the fuel used in the kiln and drying operations. The largest single source of emissions is the kiln, which may be considered to have three units: the feed system, the fuel firing system, and the clinker cooling and handling system. The most desirable method of disposal of the dust collected by a particulate control system is injection into the kiln combustion zone for inclusion in the clinker. If the alkali content of the raw material is too high, however, some of the collected dust is treated before its return to the kiln, or sold as a by-product, or discarded. Due to the complexity of modern kiln operation, and the large volume of materials being handled, many types of particulate matter control systems are used. Typical control systems include cyclones and baghouses or electrostatic precipitators. Refer to Figure 2-1 for an illustration of a typical cement kiln process.

Three cement kilns in the state have burned tires as a supplement to coal. Calaveras Cement in Redding burns tires on a permanent basis. The other two (RMC Lonestar, Davenport, and Southwestern Portland, Victorville) have performed test burns as part of the permit modification process and to obtain data needed to decide whether it is feasible and cost effective to burn tires. Each of these existing coal-fired cement kilns is of the preheating and precalcining design. To best evaluate the impact of burning waste tires as a supplement to coal-firing, data is needed during both fuel-firing scenarios at each facility (i.e. coal-only and coal-with-tires). Although coal-only data is not available for the Calaveras Cement facility, data is available for both fuel-firing scenarios for the remaining two facilities. Both facilities were required to conduct testing for certain toxic air pollutants pursuant to the requirements of the Air Toxics "Hot Spots" Act (Health and Safety Code §44300 *et seq.*). This testing was conducted in 1990 at both facilities while firing coal only. Since that time each facility has repeated the testing while firing both coal and tires simultaneously. Descriptions of each facility and summaries of the available test data appear in Appendix B.

The results of air pollutant emissions testing at RMC Lonestar and Southwestern Portland indicate that burning 18 to 25 percent tires (on a total heat input basis) as a supplement to coal in a precalcining type of cement kiln does not result in any appreciable difference in toxic air emissions. The results of criteria pollutant testing were also similar for both firing scenarios. The tests showed a 22 percent decrease in NOx emissions with the use of tires as a supplement to coal; however, the variation of NOx emissions is significant during normal operations. Long-term continuous emissions monitoring is necessary to verify the criteria pollutant emissions. While no coal-only data are available from Calaveras, continuous emissions monitoring for January to August, 1991, indicate that criteria pollutant emissions from co-firing about 22 percent TDF with coal at this facility are in the expected range (see Appendix F). Table 3-1 presents criteria pollutant emissions obtained during coal-only, and coal-with-tires firing scenarios for RMC Lonestar and Southwestern Portland.

In order to provide a preliminary assessment of the potential public health impact of burning tires as a supplemental fuel, the CARB used the Lonestar and Southwestern data in a screening air quality dispersion model and health risk assessment procedure. This assessment was a screening analysis only, not a refined risk assessment. The results of these analyses indicate no significant difference in risk from burning tires as compared to coal-only firing at these facilities. The results of the screening risk analyses are included in Appendix C.

### Wood Fired Boilers

Several wood fired boiler facilities in California have tried using chipped tires as a supplemental fuel. For various reasons, none of these facilities has used tires on a regular basis. Most of the

**TABLE 3 - 1**

COMPARISON OF EMISSIONS FROM CALIFORNIA CEMENT KILNS

| | **RMC Lonestar Davenport, 1** | | | **Southwestern Victorville, 2** | | |
|---|---|---|---|---|---|---|
| | Coal Fired | TDF Co-Fired | Percent Change | Coal Fired | TDF Co-Fired | Percent Change |
| Test Date | 4/90 | 12/90 | | 3/90 | 4/91 | |
| Percent TDF (of total heat input) | 0 | 18 | | 0 | 25 | |
| NOx (as $NO_2$) | | | | | | |
| lb/hr | 207 | 162 | **-22** | 626 | 488 | **-22** |
| lb/ton clinker | 2.1 | 1.6 | | 5.3 | 4.2 | |
| lb/MMBTU | 0.59 | 0.46 | | 1.5 | 1.2 | |
| Permit Limit | 250 lb/hr (24 hr. ave.) | | | (note 1) | | |
| $SO_2$ | | | | | | |
| lb/hr | 43 | 45 | **+5** | 4.0 | 0.3 | **-93** |
| lb/ton clinker | 0.43 | 0.45 | | 0.034 | 0.0026 | |
| lb/MMBTU | 0.12 | 0.13 | | 0.0096 | 0.00072 | |
| Permit Limit | 250 lb/hr (24 hr. ave.) | | | (note 1) | | |
| CO | | | | | | |
| lb/hr | 257 | 244 | **-5** | 250 | 538 | **+115** |
| lb/ton clinker | 2.5 | 2.4 | | 2.1 | 4.6 | |
| lb/MMBTU | 0.73 | 0.70 | | 0.60 | 1.3 | |
| Permit Limit | NA[2] | NA | | (note 1) | | |
| Total Particulates | | | | | | |
| lb/hr | NA | NA | NA | 11.0 | 6.3 | **-43** |
| lb/ton clinker | NA | NA | | 0.094 | 0.054 | |
| lb/MMBTU | NA | NA | | 0.026 | 0.015 | |
| Permit Limit | 40 lb/hr | | | (note 1) | | |
| THC (as methane) | | | | | | |
| lb/hr | NA | NA | NA | 11.5 | 6.40 | **-44** |
| lb/ton clinker | NA | NA | | 0.098 | 0.05 | |
| lb/MMBTU | NA | NA | | 0.028 | 0.02 | |
| Permit limit | NA | NA | | (note 1) | | |

Notes: 1 Facility permit limits are for combined emissions which include kilns 1, 2, 8 and 9.
2 NA means data are not available.

problems were related to increases in particulate matter emissions; however, one traveling grate boiler experienced operational problems due to slag formation from the steel wire in tires. There are little emissions data available from these operations.

One evaluation was performed in 1982 of the impact of supplementing hogged-fuel with shredded rubber tires in various percentages of fuel input at Roseburg Lumber Company in Anderson. A summary of test results appears in Appendix D. The addition of as little as three percent shredded tires caused PM emissions to almost double, with the majority of the increase attributable to lead and zinc oxides. The addition of tires also resulted in increased nitrogen oxide and sulfur oxide emissions. Although the increases were appreciable, the increase in particulate matter was the limiting factor in permitting long-term operation. Subsequent to this evaluation, the facility's permit was modified to burn three to five percent of fuel as tires. According to the facility operator, however, they stopped burning tires in 1987 because of environmental reasons (CARB, 1991b).

Staff of the air pollution control districts who were contacted have indicated that other biomass facilities which have tried burning small amounts of chipped tires experienced similar problems with particulate emissions; however, facility and equipment descriptions are not available, and operating parameters are unknown. There are no California biomass facilities known to be currently burning tires as a supplemental fuel.

Comparative air emissions of some criteria pollutants and metals from two U.S. pulp and paper mills are summarized in Appendix E. Emissions of nitrogen oxides, sulfur oxides, particulate matter, and total hydrocarbons showed no significant change when burning up to 14.5 percent dewired TDF during tests conducted in 1989 at Champion International in Bucksport, Maine (refer to Section 2.4.2 for facility information). The primary fuels used are a combination of fuel oil, biomass, coal, and non-Kraft process wastewater sludge. Particulate emissions are controlled by an ESP. Emissions of beryllium and chromium decreased, while emissions of cadmium and zinc increased.

Emissions of PM and some PAH showed significant increases at Port Townsend Paper Company in Port Townsend, Washington, during tests conducted in 1986. Air pollution control equipment included a multiclone and a venturi scrubber, but no higher-efficiency particulate controls such as a baghouse or an ESP. The primary fuels burned are a combination of wood and fuel oil. When oil was replaced with about five percent TDF (by heat input), an increase of 26 percent in particulate emissions was observed. Emissions of barium, cadmium, chromium, lead, and vanadium, however, were reduced by 36 to 99 percent. Zinc emissions dramatically increased as expected. Most PAH emissions showed no significant change with the exception of four compounds.

Performance and air pollutant emissions tests will need to be conducted prior to using tires as a fuel supplement at any facility. Results of these tests would be used to determine whether or not TDF is a compatible fuel for these facilities, with consideration for process performance, economics, and environmental impacts. It may be possible for some biomass facilities which are equipped with adequate emissions controls to burn a small amount of TDF without significant environmental impacts (refer to Section 2.4.3). Future studies to analyze such impacts should be closely coordinated with the local air pollution control district and the CARB.

#### Asphalt Production

Another potential source of air emissions associated with waste-tire rubber use is hot mix asphalt facilities. Tire rubber is heated and mixed with the bitumen binder often with the addition of additives (US EPA, 1991). Air pollutant emissions from the production of asphalt concrete may be increased due to the addition of tire rubber (or any petroleum derivative) to the bitumen binder. Emissions are also released during the application of asphalt concrete (with or without tire rubber). Further testing is needed to determine if any significant difference exists between RUMAC or AR and conventional asphalt concrete.

According to the Congressional Record, the Canadian Government has completed a study on AR and RUMAC (unavailable at this time) that indicates no additional risk due to the use of tire rubber (Congressional Record, 1991).

The Asphalt Rubber Producers Group supported an ambient air sampling program to evaluate emissions from asphalt-rubber paving. Data was compared to background concentrations of the South Coast Air Basin compiled by the South Coast Air Quality Management District. The following conclusions are based on the documentation from the sampling program (Roberts Environmental Services, 1989).

- Volatile organic sample analysis indicated low or average concentrations compared to background concentrations.
- Formaldehyde and sulfur dioxide samples collected represent "good air quality" in the South Coast Air Basin.
- Numerous exceedances in opacity, based on South Coast Air Quality Visible Emissions rule 401, were recorded.
- Meteorological conditions during the tests appeared quite typical of conditions expected for higher emissions in the South Coast Air Basin.

#### Transportation and Processing

Waste tire use can also indirectly cause air emissions from the increased amount of transportation needed to haul tire material to processors and also from the equipment required to process whole tires. Traditional types of aggregate are often acquired locally for each paving job.

Emissions from the transportation of waste tires are attributable to internal-combustion-engine exhaust (mainly diesel engines). Tractor trailer hauling is the most common form of transportation for tires (whole or shredded). Much transportation, however, is done by light and medium trucks, and rail hauling is also an alternative.

Similarly, the emissions from tire processing equipment result from diesel engine exhaust from shredders and chippers. Types of emissions generated are carbon monoxide, nitrogen oxides, sulfur oxides, particulate matter, and other products of incomplete combustion.

### 3.3.2 Surface and Ground Water Contamination

Many uses of waste tires may create potentially harmful constituents (primarily metals and PAH) which can be leached into the environment (surface and ground water supplies). Potential sources include tires used in reefs and break waters, road base, bulking agents in sludge composting, playground cover, and soil amendments.

As mentioned in Section 2.3.2, a study conducted for the Minnesota Pollution Control Agency found that metals and PAH are leached from tire rubber under certain conditions. Metals were leached in the highest concentrations under acidic conditions, while PAH were leached in the highest concentrations under basic conditions. Water samples collected for the study were found to exceed the recommended allowable limits for barium, cadmium, chromium, and lead, while background samples did not (Twin City Testing Corp., 1990). Asphalt materials, however, may leach higher concentrations of the constituents under certain conditions.

As discussed in Section 2.3.3, the EPA evaluated tire chips as an alternate bulking agent in sewage sludge composting. According to the EPA, "Heavy metal levels increased during composting with raw primary sludge and rubber chips as a result of the concentrating effect of organic matter decomposition. In addition, the shredded rubber chips contributed Zn and Fe [zinc and iron] to the finished compost." The levels would not limit the use of tire chips in sewage sludge composting (Higgins, 1987).

The Tire Pond, a North Haven, Connecticut firm, stores waste tires in a 30-acre lake. Twice a year, the water quality of the lake and surrounding ground water is determined through sampling of the lake and three wells. Based on reports from 1988 and 1989, there do not appear to be any significant changes in surface or ground water quality attributable to the stored tires. Test samples showed increased levels of iron, zinc, and sulfate; but, because of the high degree of industrialization in the area, it was difficult to determine the source of contaminants (Environmental Consulting Laboratory, 1988-1989; Tire Salvage, Inc., 1990).

Due to the differences in test subjects, methods, and objectives, no factual conclusions can be determined except that potentially harmful constituents from tire rubber can leach into the environment under specific conditions.

### 3.3.3 Wastes and By-Products

Industries other than cement kilns which use waste tire rubber as a fuel may generate wastes or by-products which are contaminated. Bottom ash and fly ash generated at combustion facilities using waste tire rubber may be contaminated with heavy metals or other constituents.

Because fly and bottom ash from biomass combustion facilities are often used as a soil conditioner on agricultural land, potential contamination due to tire-rubber combustion may limit the use of the ash. If found to be contaminated, the ash may be classified as hazardous waste and require treatment or disposal in a Class 1 landfill. Because of these and other concerns, biomass facility owners may be hesitant to use a significant amount of waste tire rubber as a fuel supplement.

Wastes and by-products are also generated by waste-tire processing industries including buffing and granulated rubber production. Due to the nature of production buffing operations, the tire carcass is not used and requires disposal. Granulated rubber production, using ambient or cryogenic processing, leaves the steel and fabric for recycling or disposal.

## 3.4 ECONOMIC ISSUES

Economic impediments to the use of waste tire rubber are the costs of collection, transportation, preparation, and capital and operating expenses. Development of markets for new products and competition with existing processes, materials, and products have also economically impeded waste tire use.

Scrap tires should be considered a resource rather than a waste material. Technically, there are many methods available to recycle tires. There must, however, be a consideration of economics, which is strongly driven by market conditions, because a reuse or recycling option will only be realistic if it is economically competitive with other products or materials.

### 3.4.1 Collection and Transportation Costs

Tires are collected from dealers and service stations by tire jockeys (people who collect, sell, and dispose of used tires) for a fee of $.35 to $1.25 for light-duty tires and $.65 to $6.00 for heavy-duty tires (NTDRA, 1990). The tire jockeys sell as many tires as possible to tire retreaders and other tire processors to generate another source of income. Ultimately, the remaining tires are landfilled, stockpiled, exported, or illegally dumped.

The cost of transportation to a waste tire user may be an economic barrier to the use of waste tires. Due to factors such as labor, truck maintenance, fuel requirements, and profit margins, trucking firms may charge as much as $.75 per tire. Maak tire, a Spokane, Washington-based firm, charges approximately $.50 per tire, or about $500 per semi-load (Pyro Recovery and Huston Trust, 1990). Calaveras Cement Company in Redding, California, pays approximately $1.35 per mile for delivery of a load of whole or shredded tires (Siemering, 1991). Consolidated Environmental Industries (CEI), a West Sacramento-based mobile tire shredding company, is charged $65 per hour (about $.06/tire/hour) for transportation of ten tons of shredded tires to either a company-owned monofill or a public landfill. CEI must also pay a tipping fee of $75 per load (about $.07/tire) at the monofill, or $140 per load (about

$.13/tire) at a landfill. For its shredding and disposal services, CEI receives $.50 per light-duty tire, and $2.50 per heavy-duty tire (Gorney, 1991).

An economic incentive for waste tire use is the deferred expense of landfilling. By not landfilling the tire material, additional capital can be used for research or market development activities. As landfill fees rise, markets for used tires are improved economically, although the impetus toward illegal dumping will also increase.

### 3.4.2 Processing Costs

Another impediment to the use of waste tires is preparation or processing costs, typically shredding. Shredding or chipping costs will vary depending on the size of the output required and the quantity of tires processed. Generally, the greater the size reduction, the greater the cost. Shredding tires can cost $15-$20 per ton (about $.14-$.18 per tire), while chipping tires (two inch) can cost $25-$35 per ton (about $.23-$.32 per tire) (Bungay, 1991; Siemering, 1991). Granulated rubber production is also expensive because of the degree of processing required. Ten to 30 mesh rubber particles can be produced for $150 to $240 per ton (about $.75 to $1.20 per tire, assuming ten pounds of rubber material recovered per tire) (SCS Engineers, 1989).

Processing tires cryogenically is also costly due to the high cost of the processing equipment and the liquid nitrogen required to "freeze" the tires prior to processing. Liquid nitrogen costs about $.07 per pound (excluding transportation costs, volume adjustments, and delivery frequency), and three-tenths to one pound of liquid nitrogen is needed to "freeze" one pound of rubber. This results in liquid nitrogen costs of $.27 to $.91 per tire processed (Carey, 1991; Gaines, et al., 1979; Kearny, 1990; Sladek, et al., 1989). The total production cost for cryogenically-produced granulated rubber is about $.12 to $.20 per pound or about $1.68 to $2.80 per tire (assuming 14 pounds of rubber material recovered per tire) (Pilorusso Research Assoc., et al., 1991).

### 3.4.3 Capital and Operating Costs

Capital and operating costs may impede the use of waste tires by many industries including cement manufacturers, electricity producers, and asphalt producers. The costs incurred for constructing new or for retrofitting existing plants, or adding environmental controls, may prevent industries from considering using tires.

#### Processing

Tire shredding and chipping companies must overcome high capital and operating costs. Saturn Shredders, a Texas-based shredder manufacturer, markets shredders ranging in price (11/90) from $202,500 to $320,000 (Saturn Shredding Systems, 1990). Columbus McKinnon Corporation, a New York-based firm, sells stationary and portable tire shredders for $410,000 and $500,000 (5/90), respectively (Columbus McKinnon Corp., 1990). Shredding Systems, Inc. (SSI), based in Wilsonville, Oregon, markets tire shredding systems ranging in cost from $66,000 to $615,000, depending on the throughput and the output shred or chip size (SSI Shredding Systems, 1991).

Consolidated Environmental Industries (CEI) of West Sacramento operates a shredder valued at approximately $385,000 (6/91). According to CEI, the cutter blades for their shredder may be sharpened once (for $4,000) and then replaced (for $12,000) after about six years of shredding (or every 100,000 tons of tires processed). Each maintenance operation requires about three days of down time for the shredder. Cutter blades can also crack and break, destroying other costly components of the shredder, as well as shutting the operation down. The shredder at CEI is powered by a 400 hp diesel engine, requiring about 50 gallons of fuel per five-hour operating day. Operating and feeding the shredder requires two to four laborers, at a cost ranging from $60 to $200 per day. In addition, other unexpected costs can occur; for example, a broken transmission cost CEI $4,000 to replace (CEI, 1991). Summing the estimated costs over the projected six-year period (approximate time required to shred 100,000 tons of tires), the costs equate to $.02 to $.05 per tire (based on an 18 pound average). Coupled with the transportation and disposal costs (see Section 3.4, transportation), the expense increases to $.15 to $.23 per tire.

A cryogenic processing system requires a significant capital investment. A facility of this type requires many pieces of equipment, including a cryogenic freezing chamber, a liquid nitrogen holding tank, a hammermill, a magnetic separation system, and possibly a granulator for further processing. Excluding site and facility expenses, a cryogenic processing system would cost about two to three million dollars (Baker Street Chemical, Inc. and North American Crumb, Inc., 1991).

### Use

Capital costs for equipment modifications may be economic barriers to industries using (or proposing to use) whole or chipped tires as a fuel supplement. For example, cement manufacturers must usually invest in new storage, handling, and conveyance systems. Both the Southwestern Cement Company in Victorville and Calaveras Cement Company in Redding have invested between $250,000 and $500,000 for whole or chipped tire handling systems (Juell, 1991; Sheets, 1991). Cementos Mexicanos, operators of a cement manufacturing plant in Ensenada, Mexico, invested about $800,000 in a handling and conveyance system for tire rubber (whole, chopped, or shredded) (Stevens, 1991).

The biomass waste-to-energy industry may be required to invest capital prior to burning tires as a fuel supplement. Some of these facilities would require feed handling and air pollution control improvements. Because many biomass facilities are permitted to burn only wood wastes, which are inherently low in sulfur, extensive air pollution control has not been required. To burn a significant amount of tire rubber in an environmentally safe manner, however, acid gas control and more efficient particulate matter control (perhaps costing millions of dollars) may be required.

Use of tire rubber in the road construction industry is also hindered by the capital and operating costs. The limited use of both RUMAC and AR have demonstrated that initial costs are higher than for conventional asphalt construction, due in part to the cost of processed rubber and the modifications required for the asphalt binder process (e.g. blending and pumping).

The Iowa Department of Natural Resources has reported that asphalt-rubber costs 65 to 70 percent more than conventional roadway construction (Iowa Department of Natural Resources, 1991). The Florida Department of Transportation estimated that inclusion of tire rubber in asphalt binders increased the overall cost 46 percent (Ruth, 1991). The Orange County Register reported that according to Manhole Adjusting Inc., traditional asphalt costs about $35 per ton, while asphalt-rubber costs about $65 per ton (46 percent increase) (Thomsen, 1991).

According to Caltrans, "The cost of asphalt-rubber binder is about three times the cost of conventional asphalt. This increases the cost of [asphalt rubber concrete] by about 40 percent over that of conventional [dense graded asphalt concrete]." Because the applications have been small, the cost for the asphalt-rubber binder has been high. The asphalt-rubber binder can be cost effective if thinner sections provide a comparable service life (Van Kirk, 1989).

Based on cost estimates from Caltrans, a 0.15 foot thick section of Plusride costs about twice as much ($6.32/yd$^2$) as a comparable section of conventional asphalt concrete ($3.04/yd$^2$). Based on initial findings, however, the service life of RUMAC is greater than that of equivalent sections of conventional asphalt concrete (Doty, 1988).

According to BAS Corporation, Plusride costs about 25 percent more per mile than conventional asphalt pavement, while the Generic Process costs about 16 percent per mile (Takallou, et al., 1989).

Even though initial costs may be higher for asphalt concrete and binders which contain tire rubber, applications often last longer and may require less maintenance. RUMAC can also be applied in thinner lifts than traditional asphalt concrete, further reducing cost differentials. Increased use in the future should also reduce the cost of RUMAC and improve its competitiveness (US EPA, 1991).

### 3.4.4 Unmarketable Products and Competition

There is a limited demand for waste-tire products due to competition from higher quality or lower cost alternatives. For example, the products from tire pyrolysis (oil and carbon black) are often difficult to sell for these reasons. Similarly, competition from other products can pose economic barriers to tire processors. Tire retreaders face competition from less expensive domestic and imported tires. Also, the reclaimed rubber industry competes with virgin natural and synthetic rubber manufacturers.

Another impediment to waste tire use is the potential product liability for an unproven material or process. Tire manufacturers, for instance, may refrain from using a significant amount of reclaimed rubber because of the questionable quality of the material. Some tire manufacturers currently use small quantities of reclaimed rubber in specific tire components which have less stringent rubber specifications than other components. Until the quality and liability issue is resolved, tire manufacturers will use only a limited amount of reclaimed rubber (and indirectly a limited amount of waste-tire rubber).

The RUMAC and AR industries may also be impeded by liability issues regarding the use of tire rubber in paving materials (Doty, 1991). Because of the inconclusive results from RUMAC and AR testing (Ansheles, 1991; Barad, 1991), many municipalities will not allow the use of paving materials which contain waste-tire rubber. Until results are documented and specifications for RUMAC and AR materials are approved, a limited amount of tire rubber will be consumed by this industry (US EPA, 1991).

## 3.5 SITING AND PERMITTING ISSUES

Prior to a facility operator using waste-tire rubber as a fuel, permit requirements must be met. These include air quality permits, health risk assessments, and the California Environmental Quality Act (CEQA) mandates. Depending on the quantities of tires stored on-site, a permit may also be required from the CIWMB.

### 3.5.1 Air Quality Permits

Burning tires as a supplementary fuel would require an air quality permit for new facilities or require permit modification, in most cases, for existing facilities. In California, the primary responsibility for controlling air pollutant emissions from stationary sources rests with the local air pollution control districts or air quality management districts. There are currently 34 districts in the state. Each district has adopted rules which pertain to the siting of new stationary sources and the modification of existing stationary sources.

The rules of these districts require pre-construction and operational permits for most new sources which emit air pollutants or for modifications to existing sources. The rules that apply are source siting rules [New Source Review (NSR) and Prevention of Significant Deterioration (PSD)] and prohibitory rules. The source siting rules establish requirements for control technology and emission offsets. Prohibitory rules establish specific requirements which must be met by all new and existing sources. Prohibitory rules address items such as visible emissions, nuisance, sulfur content of fuel, and open burning. District rules must also ensure that federal New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAP) are met when applicable.

The California Clean Air Act of 1988 placed several new requirements on programs for the permitting of new and modified sources. Permit programs in districts with moderate air pollution must be designed to achieve no net increase in emissions from permitted new or modified stationary sources which emit or have the potential to emit 25 tons per year of any specified non-attainment pollutant (or its precursors). For districts with serious or severe air pollution, the permitting program must be designed to achieve no net increase in emissions of any specified non-attainment air pollutant (or its precursors) from all permitted new or modified stationary sources. The pollutants affected by these requirements are ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide.

In addition, districts have the authority and responsibility to prevent emissions of air contaminants which endanger public health. Some local districts are imposing permit conditions which require the control of toxic air pollutants including, but not limited to, pollutants which have been identified by the CARB as Toxic Air Contaminants (TAC) pursuant to Health and Safety Code (HSC) Section 39660. Unless specifically prohibited by law, districts are also authorized to establish stricter emissions standards for stationary sources than those set by law or by the CARB.

### 3.5.2 Health Risk Assessments

Health risk assessments may be required by local air pollution control districts pursuant to HSC Section 41700, as part of the environmental review process under the California Environmental Quality Act, by specific state laws such as Health and Safety Code Section 42315 (which applies to projects which burn municipal waste or refuse-derived fuel), or by district regulations adopted pursuant to HSC Section 42300 *et seq*. regarding permits.

The purpose of a health risk assessment is to determine whether emissions from a facility will result in a significant increase in the risk of illness or mortality, including the risk of cancer. The decision on the acceptability of estimated risks is made by the local district.

Risk assessments prepared pursuant to HSC Section 42315 are required to be reviewed by the CARB and the California Department of Health Services (DHS). Risk assessments are also reviewed by the CARB at the request of local districts. The CARB and the DHS staff have prepared guidelines for preparation of health risk assessments for facilities that burn nonhazardous waste. In addition, the CARB and the DHS staff have developed a risk assessment computer program to calculate chronic exposure levels, individual cancer risk, and the cancer burden.

### 3.5.3 California Environmental Quality Act

The California Environmental Quality Act (CEQA; Public Resources Code Section 21000, *et seq.*) requires state and local agencies regulating, or approving activities affecting or potentially affecting environmental quality, to give major consideration to preventing significant environmental damage or degradation.

CEQA requires preparation of an environmental impact report (EIR) which assesses the significant effects of a proposed project on the environment. The report must address a wide range of issues including air resources, water quality, toxic pollution, and land use. In the absence of significant impacts, a negative declaration may be prepared. These documents must be made available to the public and considered by public agencies making discretionary decisions about the project. CEQA goes beyond general district air quality evaluations of projects by including the cumulative impacts of the proposed project in conjunction with existing and future projects; alternatives to the project, including alternative fuels and control equipment; and mitigation measures.

New facilities, including those proposing to burn tires, would likely require an EIR. Whether existing facilities that propose to use tires as a supplemental fuel would require an EIR would depend on the potential for significant impacts, including air quality impacts.

## 3.6 SUMMARY

Many factors may impede the use of waste tires including energy requirements, quality requirements, environmental impacts, economics, and siting and permitting requirements.

Energy consumption and expense may be prohibitive because of the energy required to transport, shred, and process waste tires. Because of volume differences, transporting whole tires is less efficient than transporting shredded tires. The processing or shredding of tires also requires large amounts of energy because of tire toughness and durability.

Due to competition with virgin materials or products not using waste-tire rubber, the use of recycled materials or products using waste-tire rubber may be impeded due to the impression (or actuality) of inferior quality. Rather than compromise product quality or marketability, manufacturers have chosen to use virgin rubber instead of recycled rubber.

Alternate uses of waste tires, in general, will be impeded if environmental impacts including air emissions, water contamination, and wastes and by-products are significant and are not easily handled.

Equipment and operating expenses require substantial capital investment. Because of these economic constraints, waste tire use is impeded.

# Methods for Mitigating the Waste Tire Problem

The main criteria for assessing the feasibility of alternative uses for tires are environmental acceptability, economic viability, and volume capability. The alternative uses are ranked using these criteria and the maximum number of tires which could be consumed is estimated.

The CIWMB should foster the development and implementation of those waste tire uses which have the greatest near-term and long-term potential to significantly reduce the number of tires requiring disposal, as well as to reduce the current volume of stockpiled tires.

## 4.1 RANKING OF ALTERNATIVES

The various methods for using tires that have been presented in this report are listed in Table 4.1. From the table it is possible to see how the methods rank in their potential to consume large quantities of tires. Most of the methods for using tires to create new products could consume only a small quantity. Products such as playground equipment, mats, or crash barriers fall in the zero to one million range for the potential consumption of tires, and these uses result in a product which will need ultimate disposal. Exporting waste tires is an option which could be quickly developed to a large scale. The main benefits could be use of the tire through the complete life of the tread (below the legal tread limits) and the elimination of the problem of disposal in California. After export, however, control of the method of disposal is lost, and if the tires are used as fuel (the most likely case), they will probably be used at facilities without adequate pollution controls.

The major potential consumer of large amounts of waste tires for the term is clearly fuel use. The cement manufacturing industry could use all of the waste tires generated in the state as well as the existing stockpiles. A further advantage of the fuel use alternative is the location of the facilities most likely to use tires. Most of the cement kilns and biomass facilities are in rural areas adjacent to urban centers or near existing tire stockpiles. Such locations allow for solid-fuel use and acceptable hauling costs. An examination of the relative location of waste tires and end-users follows.

## 4.2 MATCHING THE SOURCES AND POTENTIAL USERS OF WASTE TIRES

Transportation and processing costs are impediments to the use of waste tires. By reducing the distance the tires must be transported and the degree of processing required, the cost, as well as the fuel consumption and air emissions associated with transportation and processing, can be minimized. It is beneficial, therefore, to match the existing tire stockpiles and the major tire generation regions (population centers) with the industries having the greatest potential to consume a significant amount of tires.

The state can be divided into sub-regions apportioned on the basis of population and geographical aspects. In this way a direct comparison between the regional generation and potential consumption can be made. For the purposes of this report, county lines were used as boundaries and the sub-regional boundaries are conceptual in nature. Figure 4-1 shows the six regions and the counties within them. Also shown are the locations of the cement manufacturing and biomass waste-to-energy facilities which were identified in Section 2 as having the greatest potential to use tires as fuel. Table 4-2 lists the counties and their

**TABLE 4 - 1**

ALTERNATIVE USES FOR USED TIRES

| Alternative Uses | Potential Tire Use (millions/year) | Advantages | Disadvantages |
|---|---|---|---|
| Cement Manufacturing Facilities | 1.7-25 | Completely Disposes of Whole tire<br>Compatible with Existing Process<br>Conserves Natural Resources<br>Tests show reduced NOx Emissions | Possible Increase in Some Emissions<br>Public Acceptance<br>Long Permitting Process |
| Tire-to-Energy Facilities | 5 | Electricity Production<br>Conserves Natural Resources | Long Payback Period<br>Public Acceptance |
| Retreading | 3-4 | Extended Life of Tire<br>Saving of Resources | Declining Market<br>Limited Potential to Expand |
| Export | 1-3 | Eliminates Disposal in California | Increased Emissions from Transportation |
| Reuse | 1-2 | Full Life of Tire | Eventual Disposal Required<br>Limited Potential to Expand |
| Rubber-Modified Asphalt Concrete | 0.5-5 | Reduced Maintenance<br>Abrasion Resistance<br>Noise Reduction<br>Deicing Characteristics | Conflicting Test Results<br>High Initial Costs<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| Asphalt-Rubber | 0.5-5 | Increased Ductility<br>Improved Crack Resistance | Conflicting Test Results<br>Specialized Equipment Required<br>High Initial Cost<br>Significant Energy Requirements<br>Does Not Use All of Tire |
| Road Base, Fill, or Alternative Cover | 0-3 | Perform Well | Potential Leachate Generation |
| Sealcoating and Roofing | 0-3 | Reduced Cracking<br>Reduced Crack Severity | Higher Costs<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| Crash Barriers/ Dock Bumpers | 0-1 | Perform Well<br>Inexpensive | Limited Market<br>Eventual Disposal Required |
| Erosion Control | 0-1 | Perform Well<br>Inexpensive | Limited Market<br>Eventual Disposal Required |
| Agriculture | 0-1 | Inexpensive | Limited Market<br>Eventual Disposal Required |
| Reefs | 0-1 | Increases Fish Habitation<br>Durable | Expensive to Install<br>Potential Instability |
| Breakwaters | 0-1 | Inexpensive<br>Perform Well<br>Durable | Limited Market<br>Potential Instablity |
| Fencing/Playground Equipment | 0-0.5 | Inexpensive<br>Does Not Degrade | Only Non-Steelbelted Tires Used<br>Aesthetics<br>Limited Market |

CONTINUED ON THE NEXT PAGE

**TABLE 4 - 1** CONTINUED FROM THE PREVIOUS PAGE

## ALTERNATIVE USES FOR USED TIRES

| Alternative Uses | Potential Tire Use (millions/year) | Advantages | Disadvantages |
|---|---|---|---|
| Fabricated Rubber Products | 0-2 | Performs Well<br>Durable | Limited Potential to Expand<br>Limited Market |
| Flooring (Mats) | 0-0.5 | Performs Well<br>Noise Reduction | Limited Market<br>Eventual Disposal Required |
| Surfacing | 0-1 | Lessens Impact | Limited Market<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| Soil Amendment | 0-1 | Increases Porosity<br>Improves Oxygen Diffusion<br>Improves Water Absorption<br>Decreases Compaction | Potential Leachate Generation<br>High Cost<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| Composting (Bulking Agent) | 0-1 | Non-Biodegradable<br>Less Wood Debris in Product<br>Lower Cost over Time | Metals and PAHs Leached into Product<br>Eventual Disposal Required<br>Limited Market |
| Playground Cover | 0-1 | Does Not Degrade<br>Performs Well | Only Non-Steelbelted Tires Used<br>Limited Market |
| Surface Treated Granulate | 0-1 | Strengthened Bonding with Other Materials | High Cost<br>Limited Market<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| New Rubber Products | 0-1 | Variety of Products | Limited Markets<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| Reclaimed Rubber (Tire Manufacturing) | 0-0.5 | Conserves Natural Resources | Loss of Elasticity<br>Performance Loss<br>Does Not Use All of Tire<br>Significant Energy Requirements |
| Pulp/Paper Plants | 0-1 | Supplements BTU Content | Limited Addition to Existing Fuel<br>May Require Significant Investment in Emission Control |
| Biomass Facilities | 0-11 | Supplements BTU Content | May Require Significant Investment in Emission Control<br>Possible Ash Contamination<br>Potential Handling/Combustion Problems<br>Limited Addition to Existing Fuel |
| MSW Facilities | 0-4 | Supplements BTU Content<br>Compatible With Existing Process | Limited Addition to Existing Fuel |
| Pyrolysis | 0-5 | Resource and Material Recovery | Limited Markets<br>Low Value Products<br>High Capital Costs |

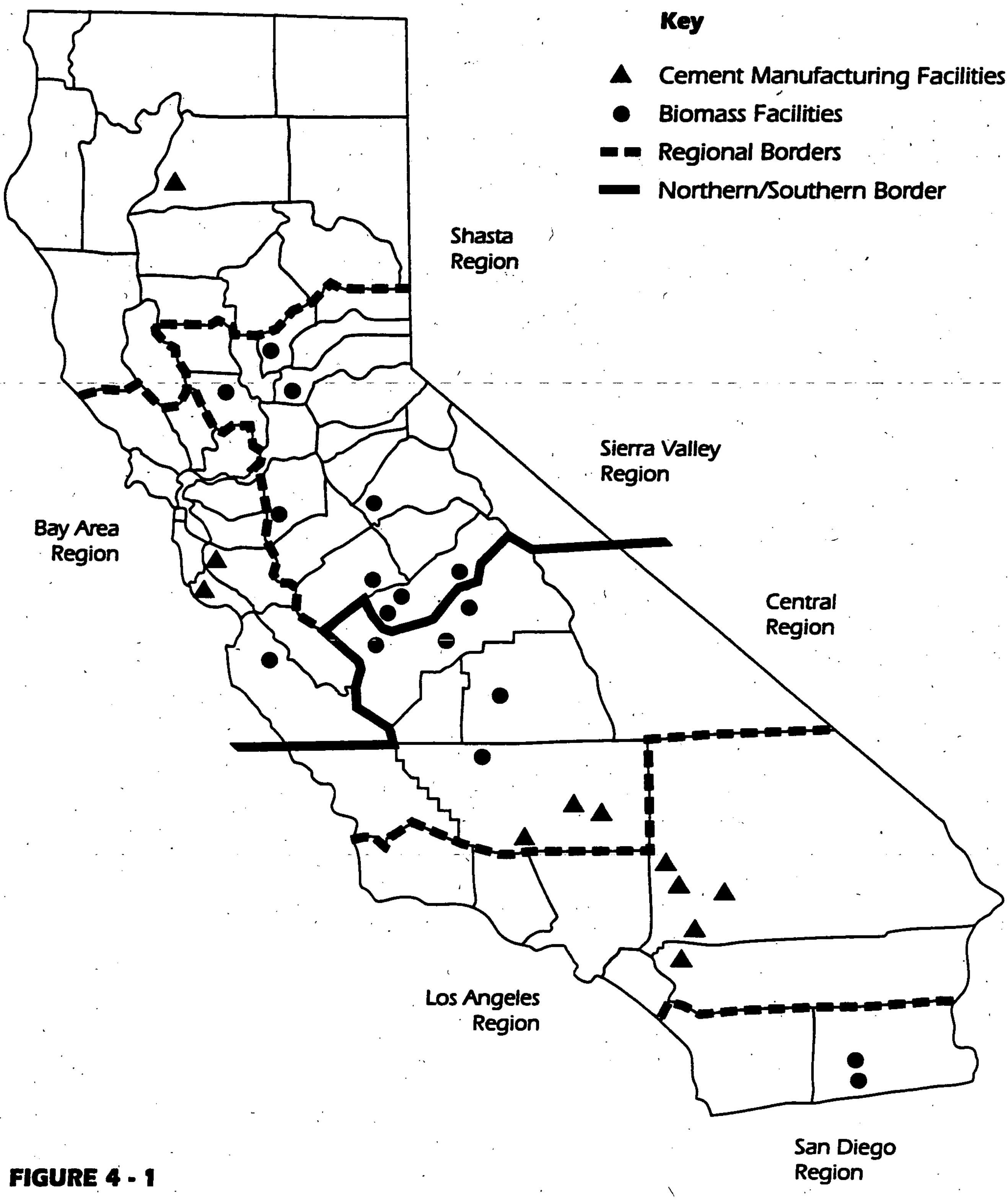



**FIGURE 4 - 1**

LOCATION OF CEMENT MANUFACTURING
AND SELECTED BIOMASS COMBUSTION FACILITIES
AND THE REGIONS OF USED TIRE GENERATION

## TABLE 4 - 2

REGIONAL POPULATION (1990) AND REGISTERED STOCKPILES

| Region | Counties | Population | Stockpiles[1] |
|---|---|---|---|
| Shasta | Butte | 182,085 | 1,500 |
| | Del Norte | 22,230 | 14,300 |
| | Glenn | 24,473 | 0 |
| | Humbodt | 120,310 | 5,500 |
| | Lake | 54,165 | 14,000 |
| | Lassen | 27,515 | 0 |
| | Mendocino | 79,105 | 36,300 |
| | Modoc | 9,673 | 600 |
| | Plumas | 20,595 | 6,800 |
| | Shasta | 147,731 | 1,239,600 |
| | Siskiyou | 45,084 | 20,000 |
| | Tehama | 49,000 | 13,000 |
| | Trinity | 14,254 | 0 |
| | Total | 796,220 | 1,351,600 |
| Bay Area | Alameda | 1,265,929 | 32,000 |
| | Contra Costa | 802,993 | 1,400 |
| | Marin | 237,028 | 0 |
| | Monterey | 360,241 | 31,200 |
| | Napa | 110,657 | 500 |
| | San Benito | 36,856 | 0 |
| | San Francisco | 726,962 | 1,000 |
| | San Mateo | 640,967 | 500 |
| | Santa Clara | 1,463,530 | 10,000 |
| | Santa Cruz | 235,335 | 100,000 |
| | Solano | 339,807 | 42,400 |
| | Sonoma | 385,389 | 33,500 |
| | Total | 6,605,694 | 252,500 |
| Sierra Valley | Alpine | 1,223 | 0 |
| | Amador | 31,316 | 0 |
| | Calaveras | 34,387 | 0 |
| | Colusa | 16,163 | 0 |
| | El Dorado | 132,751 | 0 |
| | Madera | 89,134 | 5,600 |
| | Mariposa | 15,612 | 0 |
| | Merced | 179,311 | 13,500 |
| | Mono | 10,335 | 0 |
| | Nevada | 82,950 | 0 |
| | Placer | 168,038 | 6,800 |
| | Sacramento | 1,026,769 | 116,200 |
| | San Joaquin | 470,934 | 6,006,600 |
| | Sierra | 3,617 | 0 |
| | Stanislaus | 369,027 | 15,032,000 |
| | Sutter | 64,666 | 10,000 |
| | Tuolumne | 49,064 | 500 |
| | Yolo | 139,176 | 6,000 |
| | Yuba | 58,862 | 0 |
| | Total | 2,943,335 | 21,197,200 |
| **Northern Total** | | 10,345,249 | 22,801,300 |

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**TABLE 4 - 2** CONTINUED FROM THE PREVIOUS PAGE

REGIONAL POPULATION (1990) AND REGISTERED STOCKPILES

| Region | Counties | Population | Stockpiles[1] |
|---|---|---|---|
| Central | Fresno | 646,335 | 3,040,000 |
| | Inyo | 18,441 | 0 |
| | Kern | 549,114 | 46,800 |
| | Kings | 101,663 | 1,057,500 |
| | San Luis Obispo | 221,703 | 2,000,000 |
| | Tulare | 308,445 | 636,200 |
| | Total | 1,845,701 | 6,780,500 |
| Los Angeles | Los Angeles | 8,769,944 | 88,100 |
| | Orange | 2,326,211 | 12,200 |
| | Riverside | 1,110,021 | 3,000 |
| | San Bernardino | 1,423,760 | 2,596,500 |
| | Santa Barbara | 354,072 | 0 |
| | Ventura | 668,553 | 30,000 |
| | Total | 14,652,561 | 2,729,800 |
| San Diego | Imperial | 119,603 | 0 |
| | San Diego | 2,509,914 | 507,000 |
| | Total | 2,629,517 | 507,000 |
| **Southern Total** | | 19,127,779 | 10,017,300 |
| **California Total** | | 29,473,028 | 32,818,600 |

Sources: Portland Cement Association Plant Information Summary, 1989;
'90-'91 County Fact Book, County Supervisors Association of California.

Notes: [1] Stockpile size rounded to the nearest 100 tires. Totals are approximate 1991 data.

respective populations and stockpile data for each region. Nearly all of the stockpiled tires in Stanislaus county are in one location (Philbin Tire Pole) and are dedicated to the Modesto Energy Project. A majority of these tires have come from the greater San Francisco Bay area and as such should be aggregated with that sub-region.

### 4.2.1 Cement Manufacturing Facilities

California cement manufacturing facilities, due to their locations and large energy requirements, could consume all of the tires generated in the state using a minimal amount of transportation. Of the 11 facilities in California, ten are in or near densely populated areas where large quantities of waste tires are generated (see Figure 4-1). In addition, many existing stockpiles are located near these facilities.

The three cement manufacturing facilities in northern California are located in Redding, Permanente (north of Cupertino), and Davenport (north of Santa Cruz). The remaining eight facilities are located in southern California at Lebec, Tehachapi, Mojave, Oro Grande, Victorville, Lucerne Valley, Colton, and Riverside. These eight facilities are located adjacent to the Los Angeles area, approximately 40 to 60 miles away. Table 4-3 illustrates the potential waste tire consumption by the cement manufacturing facilities by region and also the tire generation rates by region.

Three estimates of tire generation rates are shown in Table 4-3. The first estimate is based on the nationally recognized rate of one used tire generated per person per year. This population-based estimate yields a total of 29.5 million tires per year for California. This is higher than the used-tire estimate of 27 million developed by Board staff for this study (see Section 1.2.1). The population-based method is believed to overestimate the used-tire generation rate in California.

Because a large fraction of the used tires (as defined in this study) is recovered for reuse and retreading, it is more useful to compare the consumption potential of industries with the *waste*-tire generation rate estimate of 20.9 million. The used-tire estimates and waste-tire estimates were portioned pro rata by region as shown in Table 4-3.

The total California consumption potential of the cement industry is nearly 25 million tires per year based on the use of 20 percent as supplemental fuel and a equivalent weight of 18 pounds per tire (see Section 2.4.1). This potential consumption exceeds the generation estimate for waste tires.

### 4.2.2 Biomass Combustion Facilities

California biomass combustion facilities also have some potential to consume a significant number of waste tires; however, biomass facilities would have to be evaluated on a case-by-case basis to determine if air pollution control requirements could be met. The only test data currently available indicated a substantial increase in particulate matter, NOx, and SOx emissions when shredded tires were used as supplemental fuel. As discussed in Section 2.4.3, 57 facilities are currently operating in California, eight of which have the potential to use waste-tire rubber as a supplemental fuel. These eight facilities are within 100 miles of a large population center, and seven of the eight facilities are located within 40 miles of existing waste-tire stockpiles. These eight facilities could consume about six million waste tires per year if five percent (by weight) of the current fuel was replaced with tire rubber.

Of the remaining 49 facilities, nine (all fluidized-bed combustors) have either a baghouse or ESP for particulate matter control (similar to the first eight facilities), but do not have both nitrogen oxides and sulfur oxides controls. With modification to improve control efficiencies, these facilities may increase their potential to use waste tires as a supplemental fuel. Each of these nine is within 100 miles of a large population center, and seven of the facilities are within 40 miles of existing waste-tire stockpiles. These nine facilities could consume nearly seven million tires if five percent (by weight) of the fuel requirement was supplemented with tires.

The remaining 40 facilities either do not have high efficiency pollution control equipment (requiring substantial capital investment to install) or they have a combustor which may not be suitable for burning tire rubber as a fuel supplement, or information on the air pollution control equipment used was not available to perform a preliminary assessment of their potential. As shown on Table 4-3, the total biomass-combustion industry use potential is about 13 million tires per year.

### 4.2.3 RUMAC and AR Industries

RUMAC and AR industries have the potential to consume a significant amount of waste-tire rubber. Most of the techniques used to produce crumb rubber, granulated rubber, and buffings, however, produce significant amounts of wastes. Typically 10 to 14 pounds of product is recovered from each 18 to 20 pound tire.

Because of the quantity of size-reduced tire rubber required for AR and RUMAC paving and the expense of transporting whole tires, tire processors located in or near heavily populated regions with high waste-tire generation rates would be best suited to collect large quantities of tires. The size-reduced tire material could then be transported more economically than whole tires. Because heavily populated regions have proportionally more surfaces requiring pavement, the tire material would also not need to be transported as far for its ultimate use.

According to the *Daily News* (Los Angeles), the Asphalt-Rubber Producers Group reports that since Asphalt-Rubber was introduced in California in 1983, about 2.7 million waste tires have been used

**TABLE 4 - 3**

COMPARISON OF USED AND WASTE TIRE GENERATION AND POTENTIAL USE BY REGION
(Millions of tires per year, 1990)

| Region | EPA Population Based Method of Estimating Tire Generation Rates | Estimated Used Tire Generation From This Study (Section 1.2.1) | Estimated Waste Tire Generation From This Study (Section 1.2.1) | Waste Tire Consumption Potential: Cement | Waste Tire Consumption Potential: Biomass |
|---|---|---|---|---|---|
| Shasta | 0.8 | 0.7 | 0.5 | 1.7 | - |
| Bay | 6.6 | 6.1 | 4.7 | 5.9 | 0.4 |
| Sierra Valley | 2.9 | 2.7 | 2.1 | - | 6.7 |
| **Northern Total** | 10.3 | 9.5 | 7.3 | 7.6 | 7.1 |
| Central | 1.8 | 1.7 | 1.3 | 5.4 | 3.4 |
| Los Angeles | 14.7 | 13.4 | 10.4 | 11.7 | - |
| San Diego | 2.6 | 2.4 | 1.9 | - | 2.2 |
| **Southern Total** | 19.1 | 17.5 | 13.6 | 17.1 | 5.6 |
| **California Total** | 29.4 | 27.0 | 20.9 | 24.7 | 12.7 |

(1983 to 1990) by the Asphalt-Rubber Industry (Monarez, 1991). According to Manhole Adjusting, Inc., about two million tires were used by the Asphalt-Rubber Industry between 1983 and 1989 (Manhole Adjusting Contractors, Inc., 1990). The potential consumption of waste-tire rubber by the industry exceeds the current generation of waste tires; however, the feasibility of this use has yet to be determined. The current assessment is that for the near term, Asphalt-Rubber use will continue to grow and will consume several million tires per year. Due to the energy required to produce tire buffings or granulated rubber and the costs of RUMAC and AR, the ultimate potential of this industry is limited.

## 4.3 METHODS TO OVERCOME DEVELOPMENTAL BARRIERS

Many barriers to the use of waste tires currently exist and may be generally categorized as technological, environmental, economical, and sociological.

Options for mitigating the technological barriers to waste tire use include increased research and development, testing, and technology transfer. Since waste tires have only recently been viewed as a useful commodity, there is a lack of information of alternative uses; however, an increase in research and development may stimulate the industry. Also, technology transfer could further benefit the industry by eliminating repetition of research and development efforts.

The RUMAC and AR industries, for example, could benefit from increased research and development and technology transfer. Currently, many governmental agencies and private companies are developing specifications and applying and testing pavements. Because much research and testing is performed independently, progress is delayed. Conflicting results from repetitive testing also impede progress. If research was coordinated and disseminated among the industry, however, development would proceed more quickly, and mitigation of the waste-tire problem could begin sooner.

Options for eliminating the environmental barriers to waste-tire use include demonstration projects for air pollution compliance and waste-product use. Demonstration projects promoting air pollution compliance would show the potential of tire rubber as a fuel comparable to coal for industries other than the cement industry. If proven environmentally acceptable, tires may be used for fuel on a larger scale. Similarly, if other uses can be demonstrated to be environmentally acceptable, then objections may decrease.

Options for mitigating the economic barriers to waste-tire use include tax incentives, purchase and/or disposal fees, purchase preferences, and grants and low-interest loans. Economic barriers including transportation costs processing costs, capital costs, and operating costs can be at least partially reimbursed by one or more of these options. These economic incentives would assist the waste-tire industry and encourage development. The assessment of disposal fees (landfill or stockpile) must be coupled with the availability of economical options for reuse; otherwise, illegal dumping will become the most viable and utilized option.

California offers an economic incentive in the form of a 40 percent tax credit, up to $250,000 for equipment which produces products which are composed of at least 50 percent secondary waste. A minimum of ten percent of the secondary waste must be post-consumer waste. Products must have an economic value to a consumer and be ready to be used without the requirement of further alteration of its form.

Increased market development could also help mitigate the economic barriers to waste-tire use. One problem in the waste-tire industry, due in part to its recent development, is the lack of markets for tire rubber (chipped or crumbed) and tire-related products. If more markets could be developed, thereby creating an economic incentive to entrepreneurs, a greater quantity of waste tires could be used. Another consideration is to ensure that many viable options exist, regardless of consumption, such that disposal is not dependent upon industry which may be subject to downturns.

Recycling Market Development Zones selected by the Board help communities meet their waste diversion and recycling goals and stimulate economic development. State and local governments help with incentives to recycling businesses such as low-interest loans of up to $1,000,000 or one-half of the project cost, technical and marketing assistance, and manufacturer referrals. Businesses and local government agencies which are located in these zones are eligible to apply for loans for buildings, equipment, and working capital for projects which support the use of post-consumer waste.

Alternatives for overcoming sociological barriers, such as public resistance to facility siting and public perception of tire-related products, include education and demonstration projects. By educating the public about tire-related products and processes, many misconceptions and apprehensions may be eliminated.

## 4.4 RECOMMENDATIONS

In terms of value as a fuel, tires are equivalent to coal and, as such, constitute an excellent energy resource. The Board has concluded that, under the right conditions, tires can be safely burned as a fuel supplement. Use of tires in cement kilns displaces coal. That means the coal does not have to be mined or transported and, if the emissions are equivalent, an overall environmental benefit is realized because the tires are consumed in a manner that leaves no residue. Emissions tests at two California cement kilns burning waste tires with coal fuel showed no appreciable difference in toxic air contaminant emissions when compared to burning coal fuel only. The use of tires by cement kilns is a method with existing technology that could be quickly implemented, and has the potential to eliminate all of the waste tires stockpiled and generated.

The economic savings from the use of tire fuel by the cement industry will result in the payback of capital investments within about one year ($500,000 to $1,000,000). As alternative uses develop and market forces dictate, the cement industry may easily reduce or eliminate the use of tires as a fuel supplement with little impact to their operations.

The Board recommends that support be provided for the use of tires as fuel in cement kilns. To address concerns on the variability in emissions, funding for further source testing should be provided as well as assistance with air quality permitting. Other long-term methods of recycling tires must also be developed to provide diversity and avoid dependence on only one option.

The Board also recommends that support be continued for the use of Rubber-Modified Asphalt Concrete (RUMAC) and Asphalt-Rubber (AR) through additional funding of research by CalTrans, encouraging the use in maintenance applications and establishing processing specifications.

Other options for waste-tire use should be evaluated by considering factors such as the quantity of tires diverted, the costs of the option, the markets for the product, and the degree to which the option mitigates or avoids adverse environmental effects. Supporting a variety of options will aid the natural evolution of the most valuable uses and allow the marketplace to determine the flow of waste tires.

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# Appendices

## APPENDIX A

Comparison of Elemental Analysis of Tires and Other Fuels

| Element | Tires | Western Coal | MSW/RDF | Biomass* |
|---|---|---|---|---|
| | (in percent by weight) | | | |
| Nitrogen | <0.1 - 0.8% | 0.3 - 1.4% | 0.3 - 0.8% | 0.1 - 4.5% |
| Sulfur | 0.9 - 2.1% | 0.4 - 1.0% | 0.1 - 0.4% | 0.01 - 0.7% |
| Carbon | 64 - 87% | 30 - 72% | 27 - 33% | 13 - 72% |
| Hydrogen | 5 - 7% | 4 - 5% | 4% | 3 - 7% |
| Oxygen | 1 - 5% | 9 - 26% | 26% | 3 - 47% |
| Ash | 2 - 25% | 8 - 11% | 13 - 20% | 0.2 - 17% |
| Chlorine | 0.07 - 0.2% | 0.04% | 0.3 - 0.8% | |
| | (in ug/MJ) | | | |
| Aluminum | 8506 | *** | *** | *** |
| Arsenic | 61 - 120 | 20 - 537 (194)** | 23 - 2392 (380)** | *** |
| Cadmium | 110 - 184 | 2 - 179 (34) | 17 - 3538 (702) | *** |
| Chromium | 98 - 2457 | 186 - 1385 (445) | 280 - 125,623 (15,102) | *** |
| Copper | 921 | 233 - 1026 (476) | 1046 - 180,039 (26,237) | *** |
| Iron | 122,835 | *** | *** | *** |
| Lead | 1167 - 1996 | 88 - 476 (291) | 877 - 136,663 (39,290) | *** |
| Manganese | 798 | 287 - 3472 (1733) | 1059 - 48,022 (15,419) | *** |
| Mercury | 1.5 - 15 | 2 - 9 (4.6) | <130 - 362 (166) | *** |
| Nickel | 104 | 104 - 534 (288) | 90 - 51,564 (6380) | *** |
| Zinc | 460,631 - 2,333,866 | 186 - 8825 (1685) | 3018 - 303,716 (60,943) | *** |
| | (in BTU/lb) | | | |
| Heating Value | 14,000 | 12,500 | 6000 | 6500 - 8500 |

* Biomass values are the range based on field crops, orchard prunings, and forest residues. Heating values are on a dry basis.

** Values in parentheses are the average of the tests represented by the range listed.

*** No Data Available

Calculations for tires:

$$14,000 \text{ BTU/lb} \times 2.326 = 32,564 \text{ kJ/kg}$$

$$\text{ug/MJ} = \text{ppm} \times \frac{1}{\text{kJ/kg}} \times 10^6 = \frac{\text{ppm} \times 10^6}{32,546}$$

References:

1. Coal, MSW and RDF values are based on data compiled in ARB 1984 Resource Recovery Report

2. Tire values are based on data compiled in the draft ARB 1991 Resource Recovery Report update

3. Biomass values are based on data compiled in the draft ARB 1991 Resource Recovery Report update and "Fuel Analyses of Various Biomass Fuels" compiled by the California Air Resources Board, September 14, 1981.

# RMC LONESTAR, DAVENPORT

***AIR POLLUTION CONTROL EQUIPMENT:*** Electrostatic Precipitator (ESP)

***PROCESS DESCRIPTION:*** This kiln uses preheating/precalcining processing (dry type) technology. A 245 foot preheater tower is used to condition incoming raw material using recovered waste heat from the kiln's exhaust gas and from the clinker cooling process. The preheater tower incorporates a coal-fired flash calciner which transfers heat from the kiln's hot exhaust gases to the incoming raw material, heating the material from about 100 F to 1600 F. The coal-fired flash calciner requires about 60 percent of the total coal consumed at the plant. Coal is normally introduced in 1) rotary kiln exit and 2) flash calciner, which is located inside the preheater tower.

***PERFORMANCE TEST INFORMATION:*** **Background** - Performance tests were conducted April 17-18, 1990 firing coal only and on December 4-6, 1990 firing a combination of coal and tire derived fuel (TDF). During the coal/TDF performance test, 30 percent of the coal introduced into the flash calciner was replaced with TDF. TDF supplemental fuel firing into the process was limited to 2.4 tons/hr. All test samples were taken at the ESP exhaust stack (this effluent includes exhaust streams from the kiln and the roller mill). Test methods employed are listed below.
**Results** - Analysis of laboratory QA/QC, as discussed in Apendix D of the March 1991 Engineering Science (ES) test report shows that 20 of 30 internal standard recovery efficiencies for dioxins/furans were below 60 percent. The internal standard recovery is a data quality assurance check that indicates the overall performance of the analytical method employed. The CAPCOA Resource Recovery Subcommittee recommends that internal standard recovery efficiencies should range between 60 and 120 percent and any efficiencies outside of this range may mean that reported emissions could be significantly underestimated.

| *Compound* | *Test Method Employed* |
|---|---|
| Dioxins/Furans | CARB Method 428 |
| Metals | EPA Multiple Metals Method |
| Chromium | CARB Method 425 |
| Benzene | CARB Method 410A |
| Halogenated Organics | CARB Method 422 |
| Chlorides | CARB Method 421 |
| Formaldehyde | CARB Method 430e |

***Parameters Recorded***

Stack Height Above Ground = 144 feet
Stack Diameter = 10 feet
Material Feed To Kiln = 189 tons/hr (ave)
Gas Exit Velocity = 60.12 feet/sec (ave)
Gas Moisture = 11.3% (ave)
Gas Molecular Weight = 31.14 lb/lb-mole (dry) (ave)
Gas Exit Temperature = 225 F (ave)
Gas Volumetric Flow Rate = 193,399 dscfm (ave)
Carbon Dioxide Concentration = 16.8% (ave)

***PERMIT INFORMATION:*** The following information is contained in the April 1, 1988 Permit to Operate #4401 issued to RMC Lonestar by the Monterey Bay Unified Air Pollution Control District:

***Facility Permitted Emission Limits***

| | |
|---|---|
| PM | = 40 lbs/hr |
| | = 0.30 lbs/ton kiln feed |
| Opacity | = 20% (Ringlemann 1) |
| $NO_x$ | = 250 lbs/hr (24 hour average) |
| | = 350 lbs/hr (2 hour average) |
| $SO_2$ | = 250 lbs/hr (24 hour average) |
| | = 300 lbs/hr (2 hour average) |
| CEMs | = $NO_x$, $SO_x$, Opacity, Volumetric Exhaust Gas Flow Rate |

Additional permit requirements include semi-annual source testing (annual optional approval required by the district) and daily record keeping for: maximum 2 hour, 24 hour averages of $NO_x$, $SO_2$; $SO_3$ content in the kiln; kiln feed rate; hours of operation; and raw mill operation schedule.

| Facility | : RMC LONESTAR, DAVENPORT |
|---|---|
| Test Dates / Test I.D. | : APRIL 17-18, 1990 / COAL (200 tons/hr average kiln feed) |

| COMPOUND[1] | (# runs below MDL)[2] | EMISSION RATE (gms /ton feed) | (Lbs/ hr) | (gms /second) |
|---|---|---|---|---|
| $NO_x$ [3] | 0 | 4.97 EE+02 | 207 | 26.1 |
| $SO_x$ [3] | 0 | 1.03 EE+02 | 43 | 5.3 |
| PM | NO DATA | NO DATA | NO DATA | NO DATA |
| CO [3] | 0 | 6.17 EE+02 | 257 | 32.4 |
| THC | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzene | 3 | 2.0 EE-01 | 9.0 EE-02 | 1.1 EE-02 |
| Dioxins/Furans (TCDD Eq.) | 0 | 1.0 EE-08 | 4.4 EE-09 | 5.5 EE-10 |
| Formaldehyde | 0 | 2.7 EE+01 | 11.8 EE 00 | 1.5 EE 00 |
| PCB | 2 | 2.0 EE-05 | 9.0 EE-06 | 1.1 EE-06 |
| Anthracene | 1 | 7.4 EE-06 | 3.3 EE-06 | 4.2 EE-07 |
| Benzo(a)anthracene | 2 | 1.4 EE-05 | 6.2 EE-06 | 7.8 EE-07 |
| Benzo(b)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(k)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(g,h,i)perylene | 3 | 1.3 EE-06 | 5.9 EE-07 | 7.4 EE-08 |
| Benzo(a)pyrene | 3 | 3.3 EE-06 | 1.4 EE-06 | 1.8 EE-07 |
| Dibenzo(a,h)anthracene | 3 | 9.8 EE-07 | 4.3 EE-07 | 5.4 EE-08 |
| Flouranthene | 0 | 3.6 EE-05 | 1.6 EE-05 | 2.0 EE-06 |
| Indeno(1,2,3-cd)pyrene | 3 | 8.7 EE-07 | 3.8 EE-07 | 4.8 EE-08 |
| Aluminum | 0 | 7.6 EE-02 | 3.3 EE-02 | 4.2 EE-03 |
| Arsenic | 2 | 1.7 EE-04 | 7.7 EE-05 | 9.7 EE-06 |
| Barium | 0 | 1.4 EE-02 | 6.1 EE-03 | 7.7 EE-04 |
| Beryllium | 3 | 6.4 EE-04 | 2.8 EE-04 | 3.5 EE-05 |
| Cadmium | 3 | 3.8 EE-03 | 1.7 EE-03 | 2.1 EE-04 |
| Calcium | 0 | 1.5 EE 00 | 6.8 EE-01 | 8.6 EE-02 |
| Chromium (Hexavalent) | 2 | 1.2 EE-05 | 5.5 EE-06 | 6.9 EE-07 |
| Chromium (Total) | NO DATA | NO DATA | NO DATA | NO DATA |
| Chromium (Trivalent) [4] | 0 | 6.7 EE-04 | 3.0 EE-04 | 3.8 EE-05 |
| Cobalt | 3 | 2.6 EE-03 | 1.1 EE-03 | 1.4 EE-04 |
| Copper | 0 | 5.7 EE-02 | 2.5 EE-02 | 3.2 EE-03 |
| Iron | 0 | 1.6 EE-01 | 6.9 EE-02 | 8.7 EE-03 |
| Lead | 0 | 2.5 EE-03 | 1.1 EE-03 | 1.4 EE-04 |
| Magnesium | 3 | 3.8 EE-01 | 1.7 EE-01 | 2.1 EE-04 |
| Manganese | 0 | 4.1 EE-02 | 1.8 EE-02 | 2.3 EE-03 |
| Mercury | 2 | 4.7 EE-01 | 2.1 EE-01 | 2.6 EE-02 |
| Molybdenum | 3 | 3.8 EE-03 | 1.7 EE-03 | 2.1 EE-04 |
| Nickel | 3 | 6.4 EE-03 | 2.8 EE-03 | 3.5 EE-04 |
| Phosphorus | NO DATA | NO DATA | NO DATA | NO DATA |
| Selenium | 2 | 3.6 EE-04 | 1.6 EE-04 | 2.0 EE-05 |
| Silicon | 0 | 1.4 EE-01 | 6.1 EE-02 | 7.7 EE-03 |
| Sodium | 0 | 4.0 EE-01 | 1.8 EE-01 | 2.3 EE-02 |
| Strontium | 3 | 1.2 EE-03 | 5.5 EE-04 | 6.9 EE-05 |
| Titanium | 2 | 1.9 EE-03 | 8.2 EE-04 | 1.0 EE-04 |
| Vanadium | 3 | 1.2 EE-03 | 5.5 EE-04 | 6.9 EE-05 |
| Zinc | 0 | 2.2 EE-02 | 9.7 EE-03 | 1.2 EE-03 |
| Zirconium | 3 | 1.2 EE-03 | 5.5 EE-04 | 6.9 EE-05 |

1 Isomers and/or homologues not detected were added to total at 1/2 detection limit for 3 test runs.

2 This represents number of values below minimum detection limit (MDL) for 3 test runs.

3 Emissions were recorded during coal-only firing on December 4-7, 1990.

4 Trivalent chromium ($Cr^{+3}$) reported as total chromium (Cr) (see Appendix B of source test report).

| | | |
|---|---|---|
| Facility | : | RMC LONESTAR, DAVENPORT |
| Test Dates / Test I.D. | : | DECEMBER 4-7, 1990 / COAL & TIRE DERIVED FUEL (TDF) |
| Kiln Feed, tons/hr | : | 189 (average) |

| COMPOUND[1] | (# runs below MDL)[2] | EMISSION RATE (gms /ton feed) | (Lbs/ hr) | (gms /second) |
|---|---|---|---|---|
| $NO_x$ | 0 | 3.89 EE+02 | 162 | 20.4 |
| $SO_x$ | 0 | 1.08 EE+02 | 45 | 5.7 |
| PM | NO DATA | NO DATA | NO DATA | NO DATA |
| CO | 0 | 5.86 EE+02 | 244 | 30.7 |
| THC | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzene | 0 | 9.68 EE-01 | 4.03 EE-01 | 0.05 EE 00 |
| Dioxins/Furans (TCDD Eq.) | 0 | 1.32 EE-08 | 5.50 EE-09 | 6.94 EE-10 |
| Formaldehyde | 0 | 1.22 EE 00 | 5.07 EE-01 | 0.06 EE 00 |
| PCB | 1 | 6.92 EE-04 | 2.88 EE-04 | 3.63 EE-05 |
| Anthracene | 2 | 1.82 EE-04 | 7.56 EE-05 | 9.53 EE-06 |
| Benzo(a)anthracene | 3 | 8.76 EE-05 | 3.65 EE-05 | 4.60 EE-06 |
| Benzo(b)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(k)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(g,h,i)perylene | 3 | 1.65 EE-04 | 6.87 EE-05 | 8.66 EE-06 |
| Benzo(a)pyrene | 3 | 1.22 EE-04 | 5.06 EE-05 | 6.38 EE-06 |
| Dibenzo(a,h)anthracene | 3 | 2.93 EE-04 | 1.22 EE-04 | 1.54 EE-05 |
| Flouranthene | 1 | 1.29 EE-04 | 5.36 EE-05 | 6.76 EE-06 |
| Indeno(1,2,3-cd)pyrene | 3 | 9.79 EE-05 | 4.08 EE-05 | 5.15 EE-06 |
| Aluminum | 0 | 1.35 EE-02 | 5.60 EE-03 | 7.06 EE-04 |
| Arsenic | 1 | 3.24 EE-05 | 1.35 EE-05 | 1.70 EE-06 |
| Barium | 0 | 2.01 EE-03 | 8.39 EE-04 | 1.06 EE-04 |
| Beryllium | 3 | 3.27 EE-05 | 1.36 EE-05 | 1.72 EE-06 |
| Cadmium | 1 | 3.00 EE-04 | 1.25 EE-04 | 1.58 EE-05 |
| Chromium (Hexavalent) | 0 | 1.52 EE-04 | 6.31 EE-05 | 7.96 EE-06 |
| Chromium (Total) | 0 | 9.30 EE-04 | 3.87 EE-04 | 4.88 EE-05 |
| Chromium (Trivalent) | NO DATA | NO DATA | NO DATA | NO DATA |
| Cobalt | 0 | 9.75 EE-04 | 4.06 EE-04 | 5.12 EE-05 |
| Copper | 0 | 2.30 EE-03 | 9.56 EE-04 | 1.21 EE-04 |
| Iron | 0 | 3.61 EE-01 | 1.50 EE-01 | 0.02 EE 00 |
| Lead | 0 | 1.27 EE-02 | 5.27 EE-03 | 6.65 EE-04 |
| Magnesium | 0 | 3.75 EE-02 | 1.56 EE-02 | 1.97 EE-03 |
| Manganese | 0 | 2.32 EE-02 | 9.68 EE-03 | 1.22 EE-03 |
| Mercury | 1 | 2.54 EE-05 | 1.06 EE-05 | 1.34 EE-06 |
| Molybdenum | 0 | 9.16 EE-04 | 3.81 EE-04 | 4.80 EE-05 |
| Nickel | 0 | 1.65 EE-02 | 6.87 EE-03 | 8.66 EE-04 |
| Phosphorus | NO DATA | NO DATA | NO DATA | NO DATA |
| Selenium | 3 | 2.18 EE-04 | 9.07 EE-05 | 1.14 EE-05 |
| Silicon | 0 | 1.80 EE-01 | 7.49 EE-02 | 0.01 EE 00 |
| Titanium | 0 | 5.02 EE-03 | 2.09 EE-03 | 2.64 EE-04 |
| Vanadium | 3 | 3.10 EE-05 | 1.29 EE-05 | 1.63 EE-06 |
| Zinc | 0 | 5.95 EE-03 | 2.48 EE-03 | 3.13 EE-04 |
| Zirconium | 1 | 4.94 EE-05 | 2.06 EE-05 | 2.60 EE-06 |

1 Isomers and/or homologues not detected were added to total at 1/2 detection limit for 3 test runs.

2 This represents number of values below minimum detection limit (MDL) for 3 test runs.

## SOUTHWESTERN PORTLAND, VICTORVILLE

***AIR POLLUTION CONTROL EQUIPMENT:*** Fabric Filter (Baghouse)

***PROCESS DESCRIPTION:*** This kiln uses dry type processing technology and is equipped with a suspension-fired preheater. Combustion gases exiting the kiln are passed through the suspension-fired preheater section and fabric filter (baghouse) before being discharged to the atmosphere via an exhaust stack. This kiln is capable of being fired with coal or a combination of coal and tire derived fuel (TDF). The facility is currently experimenting with several locations for introducing TDF into the process including the preheater section and directly into the kiln.

***PERFORMANCE TEST INFORMATION:*** Background - Performance testing was conducted March 20-23, 1990 firing coal only and again on April 8-12, 1991 firing a combination of coal and tire derived fuel (TDF). Test methods employed for the April 1991 test are listed below. Concentrations of particulate matter, surfur dioxide, oxides of nitrogen, carbon monoxide, total hydrocarbons, hydrogen chloride, chlorine, metals, benzene, PAHs, PCDD/PCDF, formaldehyde and PM-10 were recorded during the April 1991 (coal & TDF) performance test. All emissions were sampled at the baghouse exhaust stack for both March 1990 and April 1991 performance tests. Results - TDF firing during the April 1991 (coal & TDF) performance test represented about 25 percent of total fuel input to the process. Analysis of laboratory QA/QC indicates that all internal standard recovery efficiencies for dioxins/furans were within 60 to 120 percent as recommended by the CAPCOA Resource Recovery Subcommittee. Test results for hexavalent chromium ($Cr^{+6}$) were not included in either performance test report (March 1990 or April 1991). $Cr^{+6}$ emissions were estimated as 3.11% of total chromium (Cr) emissions. This percentage is based on the ratio of $Cr^{+6}$ / Cr (total) as reported in the AB 2588 Toxics Emission Inventory Reports.

| ***Compound*** | ***Test Method Employed*** |
|---|---|
| Particulate Matter | EPA Methods 1,2,3,4 and 5 |
| PM-10 | Proposed EPA Method 201A |
| SO2 | EPA Method 6 & EPA Method 5 |
| NOx | EPA Method 7E |
| CO | EPA Method 10 |
| VOC's | EPA Method 25A |
| Metals | EPA Metals Train [1] |
| Formaldehyde | ARB Method 430 |
| Benzene | ARB Method 410A |
| Dioxins/Furans | ARB Method 428 |
| PAH | ARB Method 429 |
| HCl | ARB Method 421 |

***Parameters Recorded***

Stack Height Above Ground = 94 feet
Stack Diameter = 13 feet
Material Feed To Kiln = 216.7 tons/hr (ave)
Gas Moisture = 5.1% (ave)
Percent Isokinetic (3 runs) = 102 (ave)
Gas Exit Temperature = 409 F (ave)
Gas Volumetric Flow Rate = 181,787 dscfm (ave)
Oxygen Concentration = 10.6% (ave)
Carbon Dioxide Concentration = 16.7% (ave)

1 Draft 8/28/89 method entitled "Methodology for the Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Processes".

| | | |
|---|---|---|
| Facility | : | SOUTHWESTERN PORTLAND CEMENT, VICTORVILLE |
| Test Dates / Test I.D. | : | MARCH 20-23, 1990 / COAL |
| Kiln Feed, tons/hr | : | 224 (average) |

| COMPOUND[1] | (# runs below MDL)[2] | EMISSION RATE (gms /ton feed) | (Lbs/ hr) | (gms /second) |
|---|---|---|---|---|
| $NO_x$ | 0 | 1.27 EE 03 | 626 | 78.9 |
| $SO_x$ | 0 | 8.24 EE 00 | 4 | 0.5 |
| PM | 0 | 2.17 EE 01 | 11 (0.01 gr/dscf) | 1.4 |
| CO | 0 | 5.06 EE 02 | 250 | 31.5 |
| THC | 0 | 2.33 EE 01 | 11.5 | 1.45 |
| Benzene | 3 | 1.34 EE 00 | 0.66 EE 00 | 8.32 EE-02 |
| Dioxins/Furans (TCDD Eq.) | 0 | 1.20 EE-06 | 5.91 EE-07 | 7.45 EE-08 |
| Formaldehyde | 3 | 9.49 EE-02 | 4.68 EE-02 | 5.90 EE-03 |
| PCB | NO DATA | NO DATA | NO DATA | NO DATA |
| Anthracene | 3 | 2.43 EE-05 | 1.20 EE-05 | 1.51 EE-06 |
| Benzo(a)anthracene | 3 | 2.38 EE-05 | 1.18 EE-05 | 1.49 EE-06 |
| Benzo(b)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(k)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(g,h,i)perylene | 3 | 4.58 EE-05 | 2.26 EE-05 | 2.85 EE-06 |
| Benzo(a)pyrene | 3 | 3.95 EE-05 | 1.95 EE-05 | 2.46 EE-06 |
| Dibenzo(a,h)anthracene | 3 | 5.39 EE-05 | 2.66 EE-05 | 3.35 EE-06 |
| Flouranthene | 0 | 1.01 EE-02 | 5.00 EE-03 | 6.31 EE-04 |
| Indeno(1,2,3-cd)pyrene | 3 | 6.71 EE-05 | 3.31 EE-05 | 4.17 EE-06 |
| Aluminum | NO DATA | NO DATA | NO DATA | NO DATA |
| Arsenic | 0 | 6.28 EE-04 | 3.10 EE-04 | 3.91 EE-05 |
| Barium | NO DATA | NO DATA | NO DATA | NO DATA |
| Beryllium | 3 | 7.45 EE-05 | 3.68 EE-05 | 4.64 EE-06 |
| Cadmium | 0 | 5.88 EE-03 | 2.90 EE-03 | 3.66 EE-04 |
| Chromium (Hexavalent)[3] | NO DATA | 7.44 EE-05 | 3.67 EE-05 | 4.63 EE-06 |
| Chromium (Total) | 1 | 2.39 EE-03 | 1.18 EE-03 | 1.49 EE-04 |
| Chromium (Trivalent) | NO DATA | NO DATA | NO DATA | NO DATA |
| Cobalt | NO DATA | NO DATA | NO DATA | NO DATA |
| Copper | 0 | 8.28 EE-03 | 4.09 EE-03 | 5.16 EE-04 |
| Iron | NO DATA | NO DATA | NO DATA | NO DATA |
| Lead | 0 | 1.67 EE-02 | 8.22 EE-03 | 1.04 EE-03 |
| Magnesium | NO DATA | NO DATA | NO DATA | NO DATA |
| Manganese | 0 | 8.57 EE-03 | 4.23 EE-03 | 5.33 EE-04 |
| Mercury | 0 | 2.99 EE-03 | 1.48 EE-03 | 1.87 EE-04 |
| Molybdenum | NO DATA | NO DATA | NO DATA | NO DATA |
| Nickel | 3 | 1.28 EE-03 | 6.33 EE-04 | 7.98 EE-05 |
| Phosphorus | 0 | 1.48 EE-01 | 7.30 EE-02 | 9.21 EE-03 |
| Selenium | 3 | 4.93 EE-04 | 2.43 EE-04 | 3.06 EE-05 |
| Silicon | NO DATA | NO DATA | NO DATA | NO DATA |
| Strontium | 0 | 1.30 EE-01 | 6.40 EE-02 | 8.07 EE-03 |
| Titanium | NO DATA | NO DATA | NO DATA | NO DATA |
| Vanadium | NO DATA | NO DATA | NO DATA | NO DATA |
| Zinc | 0 | 1.14 EE-01 | 5.60 EE-02 | 7.06 EE-03 |
| Zirconium | NO DATA | NO DATA | NO DATA | NO DATA |

1 Isomers and/or homologues not detected were added to total at 1/2 detection limit for 3 test runs.

2 This represents number of values below minimum detection limit (MDL) for 3 test runs.

3 No Data for $Cr^{+6}$. $Cr^{+6}$ emissions were estimated as 3.11% of total Cr as reported in the AB 2588 Toxics Emission Inventory Reports for this facility.

| | | |
|---|---|---|
| Facility | : | SOUTHWESTERN PORTLAND CEMENT, VICTORVILLE |
| Test Dates / Test I.D. | : | APRIL 8-12, 1991 / COAL & TIRE DERIVED FUEL (TDF) |
| Kiln Feed, tons/hr | : | 216.7 (average) |

| COMPOUND[1] | EMISSION RATE (# runs below MDL)[2] | (gms /ton feed) | (Lbs/ hr) | (Notes) |
|---|---|---|---|---|
| $NO_x$ | 0 | 1.0 EE+03 | 487.8 | 61.5 |
| $SO_x$ | 0 | 6.3 EE-01 | 0.3 | 0.04 |
| PM | 0 | 1.3 EE+01 | 6.3 (0.003 gr/dscf) | 0.79 |
| CO | 0 | 1.1 EE+03 | 538 | 67.9 |
| THC | 0 | 1.3 EE+01 | 6.40 | 0.81 |
| Benzene | 3 | 3.20 EE-01 | 0.15 | 1.89 EE-02 |
| Dioxins/Furans (TCDD Eq.) | 0 | 2.06 EE-06 | 9.81 EE-07 | 1.24 EE-07 |
| Formaldehyde | 0 | 1.96 EE-02 | 9.33 EE-03 | 1.18 EE-03 |
| PCB | NO DATA | NO DATA | NO DATA | NO DATA |
| Anthracene | 0 | 2.45 EE-03 | 1.15 EE-03 | 1.45 EE-04 |
| Benzo(a)anthracene | 0 | 1.27 EE-04 | 6.05 EE-05 | 7.63 EE-06 |
| Benzo(b)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(k)anthracene | NO DATA | NO DATA | NO DATA | NO DATA |
| Benzo(g,h,i)perylene | 2 | 3.85 EE-07 | 1.84 EE-07 | 2.32 EE-08 |
| Benzo(a)pyrene | 2 | 1.35 EE-05 | 6.44 EE-06 | 8.12 EE-07 |
| Dibenzo(a,h)anthracene | *Not detected. Detection limit not given for 3 test runs.* | | | |
| Flouranthene | 0 | 1.34 EE-03 | 6.37 EE-04 | 8.03 EE-05 |
| Indeno(1,2,3-cd)pyrene | 1 | 1.04 EE-06 | 4.86 EE-07 | 6.13 EE-08 |
| Aluminum | NO DATA | NO DATA | NO DATA | NO DATA |
| Arsenic | 3 | 2.51 EE-04 | 1.20 EE-04 | 1.51 EE-05 |
| Barium | NO DATA | NO DATA | NO DATA | NO DATA |
| Beryllium | 3 | 1.05 EE-04 | 4.99 EE-05 | 6.29 EE-06 |
| Cadmium | 3 | 3.16 EE-04 | 1.51 EE-04 | 1.90 EE-05 |
| Chromium (Hexavalent)[3] | NO DATA | 5.06 EE-05 | 2.41 EE-05 | 3.04 EE-06 |
| Chromium (Total) | 1 | 1.62 EE-03 | 7.75 EE-04 | 9.77 EE-05 |
| Chromium (Trivalent) | NO DATA | NO DATA | NO DATA | NO DATA |
| Cobalt | NO DATA | NO DATA | NO DATA | NO DATA |
| Copper | 3 | 1.35 EE-03 | 6.46 EE-04 | 8.15 EE-05 |
| Iron | NO DATA | NO DATA | NO DATA | NO DATA |
| Lead | 0 | 1.36 EE-03 | 6.47 EE-04 | 8.16 EE-05 |
| Magnesium | NO DATA | NO DATA | NO DATA | NO DATA |
| Manganese | 0 | 7.68 EE-03 | 3.67 EE-03 | 4.63 EE-04 |
| Mercury | 0 | 4.05 EE-02 | 1.93 EE-02 | 2.43 EE-03 |
| Molybdenum | NO DATA | NO DATA | NO DATA | NO DATA |
| Nickel | 1 | 4.42 EE-04 | 2.11 EE-04 | 2.66 EE-05 |
| Phosphorus | 0 | 5.87 EE-02 | 2.80 EE-02 | 3.53 EE-03 |
| Selenium | 3 | 2.52 EE-04 | 1.20 EE-04 | 1.51 EE-05 |
| Silicon | NO DATA | NO DATA | NO DATA | NO DATA |
| Strontium | 3 | 1.05 EE-03 | 4.99 EE-04 | 6.29 EE-05 |
| Titanium | NO DATA | NO DATA | NO DATA | NO DATA |
| Vanadium | NO DATA | NO DATA | NO DATA | NO DATA |
| Zinc | 0 | 4.05 EE-02 | 1.93 EE-02 | 2.43 EE-03 |
| Zirconium | NO DATA | NO DATA | NO DATA | NO DATA |

1 Isomers and/or homologues not detected were added to total at 1/2 detection limit for 3 test runs.

2 This represents number of values below minimum detection limit (MDL) for 3 test runs.

3 No Data for $Cr^{+6}$. $Cr^{+6}$ emissions were estimated as 3.11% of total Cr as reported in the AB 2588 Toxics Emission Inventory Reports for this facility.

## References for Tables

1. **Engineering - Science, Inc.**, Report of Air Pollution Source Testing at RMC Lonestar Cement Company Davenport, California. Davenport, CA. Conducted April 17-18, 1990.

2. **Engineering-Science, Inc.** Report of Air Pollution Source Testing for California AB 2588 (Tire Derived Fuel) RMC Lonestar-Davenport Cement Plant. Davenport, CA. Conducted December 4-7, 1990.

3. **METCO Environmental.** Source Emissions Survey of Southwestern Portland Cement Company Kiln Number 2 Stack Victorville, California. Victorville, CA. Conducted March 1990. METCO File Number 90-20A.

4. **METCO Environmental.** Source Emissions Survey of Southwestern Portland Cement Company Kiln Number 2 Stack Victorville, California. Victorville, CA. Conducted April 1991. METCO File Number 91-64A.

## APPENDIX C
## Screening Risk Analyses

A screening air dispersion model (PTPLU) was used with default values for meteorological conditions to estimate ground level impacts expected to result during downwash conditions at RMC Lonestar and Southwestern Portland cement manufacturing facilities. Results of the air dispersion modeling were then used in conjunction with the Department of Health Services/Air Resources Board health risk assessment computer program to estimate the potential excess cancer risk associated with emissions under each fuel firing scenario. A multipathway exposure assessment approach was used which included inhalation, dermal exposure, and ingestion. The ingestion pathway of exposure included, as recommended by the California Department of Health Services, soil ingestion, mother's milk, and ingestion of homegrown produce. The results of these screening risk analyses indicated no significant difference in risk from burning tires as compared to coal-only firing at these facilities. The results of the screening risk analyses follow.

PTPLU (Version 2.0)
Analysis of concentration as a function of stability and wind speed
(California Air Resources Board Modeling Section version)

RMC Lonestar, Davenport

Source Conditions
-----------------
emission rate = 1.000 g/sec
physical stack height = 43.90 m
stack gas temperature = 380.00 deg. K
stack gas velocity = 18.30 m/sec
stack diameter = 3.00 m
volume flow rate = 129.355 m^3/sec
buoyancy flux = 92.442 m^4/sec^3

Meteorological Conditions
-------------------------
ambient temperature = 293.00 deg. K
anemometer height = 10.00 m
mixing height = 1500.00 m
Wind profile exponents: A: 0.07, B: 0.07, C: 0.10, D: 0.15, E: 0.35, F: 0.55

Receptor data
-------------
receptor elevation above ground level = 0.00 m

Options used
------------
stack downwash
buoyancy induced dispersion
rural dispersion coefficients (Pasquill-Gifford)

Results - using extrapolated winds
-------

| Stability | Wind Speed (m/sec) | Maximum Concentration (ug/m^3) | Distance of Max. (km) | Effective Height (m) | |
|---|---|---|---|---|---|
| A | 0.55 | 1.05608E+00 | 1.634 | 1099.3(2) | |
| A | 0.89 | 1.01686E+00 | 1.142 | 703.5(2) | |
| A | 1.11 | 1.14428E+00 | 1.024 | 571.6(2) | |
| A | 1.66 | 1.37775E+00 | 0.855 | 395.7(2) | |
| A | 2.22 | 1.52999E+00 | 0.756 | 307.7(2) | |
| A | 2.77 | 1.63902E+00 | 0.688 | 255.0(2) | |
| A | 3.33 | 1.71403E+00 | 0.643 | 219.8(2) | <-- MAX |
| B | 0.55 | 4.37618E-01 | 7.160 | 1099.3(2) | |
| B | 0.89 | 5.04634E-01 | 3.908 | 703.5(2) | |
| B | 1.11 | 5.89720E-01 | 3.230 | 571.6(2) | |
| B | 1.66 | 7.68964E-01 | 2.312 | 395.7(2) | |
| B | 2.22 | 9.11705E-01 | 1.843 | 307.7(2) | |
| B | 2.77 | 1.02709E+00 | 1.557 | 255.0(2) | |
| B | 3.33 | 1.12112E+00 | 1.364 | 219.8(2) | |
| B | 4.44 | 1.26109E+00 | 1.120 | 175.8 | |
| B | 5.55 | 1.35479E+00 | 0.970 | 149.4 | |
| C | 2.32 | 7.18539E-01 | 3.514 | 296.3(2) | |
| C | 2.90 | 8.30505E-01 | 2.884 | 245.8(2) | |

| | | | | |
|---|---|---|---|---|
| C | 3.48 | 9.24896E-01 | 2.470 | 212.2(2) |
| C | 4.64 | 1.07177E+00 | 1.960 | 170.1 |
| C | 5.80 | 1.17615E+00 | 1.658 | 144.9 |
| C | 8.12 | 1.30032E+00 | 1.317 | 116.0 |
| C | 11.59 | 1.36606E+00 | 1.064 | 94.4 |
| C | 13.91 | 1.40436E+00 | 0.952 | 84.9 |
| C | 17.39 | 1.43926E+00 | 0.834 | 74.9 |
| D | 0.62 | 9.99900E+15 | 999999.000(3) | 981.5(2) |
| D | 1.00 | 8.87727E-02 | 45.640 | 629.9(2) |
| D | 1.25 | 1.22795E-01 | 30.958 | 512.7(2) |
| D | 1.87 | 2.05085E-01 | 18.281 | 356.4(2) |
| D | 2.50 | 2.86106E-01 | 12.105 | 278.3(2) |
| D | 3.12 | 3.61637E-01 | 9.422 | 231.4(2) |
| D | 3.75 | 4.27656E-01 | 7.536 | 200.2(2) |
| D | 4.99 | 5.41418E-01 | 5.407 | 161.1 |
| D | 6.24 | 6.32764E-01 | 4.258 | 137.7 |
| D | 8.74 | 7.61654E-01 | 3.070 | 110.9 |
| D | 12.48 | 8.56576E-01 | 2.374 | 90.6 |
| D | 14.98 | 9.20989E-01 | 2.026 | 81.3 |
| D | 18.73 | 9.80745E-01 | 1.695 | 72.0 |
| D | 24.97 | 1.01908E+00 | 1.384 | 62.7 |
| E | 3.36 | 7.78031E-01 | 8.571 | 133.7 |
| E | 4.20 | 7.09701E-01 | 7.850 | 127.2 |
| E | 5.03 | 6.56742E-01 | 7.319 | 122.3 |
| E | 6.71 | 5.78454E-01 | 6.574 | 115.1 |
| E | 8.39 | 5.22165E-01 | 6.066 | 110.0 |
| F | 4.51 | 4.98646E-01 | 14.999 | 111.4 |
| F | 5.64 | 4.57822E-01 | 14.999 | 106.5 |
| F | 6.77 | 4.23880E-01 | 14.219 | 102.9 |
| F | 9.02 | 3.73256E-01 | 12.687 | 97.5 |
| F | 11.28 | 3.36661E-01 | 11.651 | 93.6 |

Cautionary Notes
----------------

(2) The plume is of sufficient height that extreme caution should be used in interpreting this computation as this stability type may not exist to this height. Also wind speed variations with height may exert a dominating influence

(3) No computation was attempted for this height as the point of maximum concentration is greater than 100 km or less than 1 meter from the source

CALIFORNIA AIR RESOURCES BOARD AND DEPARTMENT OF HEALTH SERVICES
HEALTH RISK ASSESSMENT MODEL
NOVEMBER 1990 VERSION

RUN BY: G.Allen
COMPANY NAME: ARB
PROJECT NAME: Lonestar/December'90/Coal&TDF
DATE OF RUN: 09-25-1991
POLLUTANT DATA FILE VERSION: 11/09/90

REPORT TYPE: CHRONIC EXPOSURE AND INDIVIDUAL CANCER RISK
******************************************************************************
EMISSION FILE NAME: c:GRAMS.E

| POLLUTANT | EMISSION RATE (G/SEC) |
|---|---|
| ALUMINUM | 7.1D-04 |
| ARSENIC, INORGANIC | 1.7D-06 |
| BARIUM | 1.1D-04 |
| BENZENE | 5.1D-02 |
| BERYLLIUM | 1.7D-06 |
| CADMIUM | 1.6D-05 |
| CHROMIUM 6+ | 8.0D-06 |
| COPPER | 1.2D-04 |
| FORMALDEHYDE | 6.4D-02 |
| IRON | 1.9D-02 |
| LEAD | 6.7D-04 |
| MAGNESIUM | 2.0D-03 |
| MANGANESE | 1.2D-03 |
| MERCURY | 1.3D-06 |
| MOLYBDENUM | 4.8D-05 |
| NICKEL | 8.7D-04 |
| PAH as BENZO(A)PYRENE | 3.2D-05 |
| PCB | 3.6D-05 |
| SELENIUM COMPOUNDS | 1.1D-05 |
| SILICON | 9.4D-03 |
| TCDD EQUIVALENT | 6.9D-10 |
| VANADIUM | 1.6D-06 |
| ZINC | 3.1D-04 |

******************************************************************************
DISPERSION FACTOR CHI OVER Q USED: .171403
******************************************************************************
ROUTE FILE NAME: c:MULTI.I

1. DEPOSITION VELOCITY IS - .02
2. MOTHER'S MILK INCLUDED - YES
3. THE FRACTION OF HOMEGROWN PRODUCE IS - .25

GENERAL ANIMAL EXPOSURE FACTORS

4. FRACTION OF ANIMAL'S DIET FROM GRAZING IS - 0
5. FRACTION OF ANIMAL'S DIET FROM IMPACTED FEED IS - 0
6. FRACTION OF ANIMAL'S WATER IMPACT BY DEPOSITION IS - 0

## ANIMAL X/Q AND WATER FACTORS

7. 

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

8. FRACTION OF MEAT IN DIET PRODUCED AT HOME IS - 0
9. THE FOLLOWING FRACTIONS OF EACH TYPE ARE PRODUCED

| BEEF | PORK | LAMB | CHICKEN |
|---|---|---|---|
| 0 | 0 | 0 | 0 |

10. FRACTION OF EGGS PRODUCED ON SITE IS - 0

## DAIRY PRODUCTS

11. FRACTION OF MILK PRODUCED ON SITE IS - 0
12. GOAT MILK FRACTION IS - 0

DRINKING WATER WILL BE EVALUATED USING THE FOLLOWING FACTORS

13. FRACTION OF IMPACTED DRINKING WATER - 0

14. 

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

FISH WILL BE EVALUATED WITH THE FOLLOWING FACTORS

15. FISH FROM IMPACTED WATER - 0

16. 

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

17. RUNOFF WILL BE EVALUATED USING THE FOLLOWING FACTORS

FACILITY HOURS OF OPERATIONS - 0
ANNUAL RAINFALL - 0
WATERSHED AREA IMPACTED - 0
WATERSHED RUNOFF COEFFICIENT - 0
WASH COEFFICIENT - 0

*****************************************************************************
RESULTS
*****************************************************************************

## CHRONIC EXPOSURE BY POLLUTANT AND ROUTE

| POLLUTANT | INHALATION (UG/M3) | INGESTION (MG/KG-DAY) |
|---|---|---|
| ALUMINUM | 1.2E-04 | 6.3E-07 |
| ARSENIC, INORGANIC | 2.9E-07 | 1.7E-09 |
| BARIUM | 1.8E-05 | 9.5E-08 |
| BENZENE | 8.7E-03 | 0.0E+00 |
| BERYLLIUM | 2.9E-07 | 1.6E-09 |
| CADMIUM | 2.7E-06 | 3.4E-08 |
| CHROMIUM 6+ | 1.4E-06 | 0.0E+00 |
| COPPER | 2.1E-05 | 1.1E-07 |

6. FRACTION OF ANIMAL'S WATER IMPACT BY DEPOSITION IS - 0

ANIMAL X/Q AND WATER FACTORS

| 7. X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

8. FRACTION OF MEAT IN DIET PRODUCED AT HOME IS - 0
9. THE FOLLOWING FRACTIONS OF EACH TYPE ARE PRODUCED

| BEEF | PORK | LAMB | CHICKEN |
|---|---|---|---|
| 0 | 0 | 0 | 0 |

10. FRACTION OF EGGS PRODUCED ON SITE IS - 0

DAIRY PRODUCTS

11. FRACTION OF MILK PRODUCED ON SITE IS - 0
12. GOAT MILK FRACTION IS - 0

DRINKING WATER WILL BE EVALUATED USING THE FOLLOWING FACTORS

13. FRACTION OF IMPACTED DRINKING WATER - 0

| 14. X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

FISH WILL BE EVALUATED WITH THE FOLLOWING FACTORS

15. FISH FROM IMPACTED WATER - 0

| 16. X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

17. RUNOFF WILL BE EVALUATED USING THE FOLLOWING FACTORS

FACILITY HOURS OF OPERATIONS - 0
ANNUAL RAINFALL - 0
WATERSHED AREA IMPACTED - 0
WATERSHED RUNOFF COEFFICIENT - 0
WASH COEFFICIENT - 0

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RESULTS

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CHRONIC EXPOSURE BY POLLUTANT AND ROUTE

| POLLUTANT | INHALATION (UG/M3) | INGESTION (MG/KG-DAY) |
|---|---|---|
| ALUMINUM | 7.2E-04 | 3.8E-06 |
| ARSENIC, INORGANIC | 1.7E-06 | 9.6E-09 |
| BARIUM | 1.3E-04 | 6.9E-07 |
| BENZENE | 2.0E-03 | 0.0E+00 |
| BERYLLIUM | 6.0E-06 | 3.2E-08 |
| CADMIUM | 3.6E-05 | 4.6E-07 |

| | | |
|---|---|---|
| CALCIUM | 1.5E-02 | 7.7E-05 |
| CHROMIUM 6+ | 1.2E-07 | 0.0E+00 |
| CHROMIUM III | 6.5E-06 | 3.4E-08 |
| COPPER | 5.5E-04 | 2.9E-06 |
| FORMALDEHYDE | 2.6E-01 | 0.0E+00 |
| IRON | 1.5E-03 | 7.8E-06 |
| LEAD | 2.4E-05 | 1.4E-07 |
| MAGNESIUM | 3.6E-03 | 1.9E-05 |
| MANGANESE | 3.9E-04 | 2.1E-06 |
| MERCURY | 4.5E-03 | 7.5E-05 |
| MOLYBDENUM | 3.6E-05 | 1.9E-07 |
| NICKEL | 6.0E-05 | 6.9E-07 |
| PAH as BENZO(A)PYREN | 1.9E-07 | 3.7E-10 |
| PCB | 1.9E-07 | 1.1E-09 |
| SELENIUM COMPOUNDS | 3.4E-06 | 0.0E+00 |
| SILICON | 1.3E-03 | 6.9E-06 |
| TCDD EQUIVALENT | 9.4E-11 | 3.2E-13 |
| VANADIUM | 1.2E-05 | 6.2E-08 |
| ZINC | 2.1E-04 | 1.1E-06 |

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INDIVIDUAL CANCER RISK BY POLLUTANT AND ROUTE

| POLLUTANT | AIR | SOIL | SKIN | GARDEN | MMILK | OTHER |
|---|---|---|---|---|---|---|
| ARSENIC, IN | 3.4D-09 | 8.6D-09 | 1.3D-10 | 4.1D-09 | 0.0D+00 | 0.0D+00 |
| BENZENE | 6.5D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| BERYLLIUM | 9.1D-09 | 1.5D-07 | 2.4D-09 | 5.8D-08 | 0.0D+00 | 0.0D+00 |
| CADMIUM | 9.5D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| CHROMIUM 6+ | 1.0D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| FORMALDEHYD | 2.1D-06 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| NICKEL | 9.1D-09 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| PAH as BENZ | 2.0D-10 | 2.6D-10 | 1.2D-10 | 2.3D-09 | 0.0D+00 | 0.0D+00 |
| PCB | 1.7D-10 | 1.3D-09 | 3.0D-09 | 1.6D-09 | 2.0D-09 | 0.0D+00 |
| TCDD EQUIVA | 2.3D-09 | 5.5D-09 | 3.9D-09 | 5.6D-09 | 7.5D-09 | 0.0D+00 |
| Route Total | 2.3E-06 | 1.7E-07 | 9.6E-09 | 7.2E-08 | 9.5E-09 | 0.0E+00 |

Total Risk 2.5E-06

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FOR CALIFORNIA AIR TOXICS HOT SPOTS ACT PURPOSES ONLY
ADDITIONAL SCREENING RISK BY POLLUTANT AND ROUTE

| POLLUTANT | AIR | SOIL | SKIN | GARDEN | MMILK | OTHER |
|---|---|---|---|---|---|---|
| LEAD | 1.2D-10 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| MERCURY | 2.2D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| SELENIUM CO | 3.0D-10 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| Route Total | 2.3E-08 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

Screening Total 2.3E-08

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END OF REPORT

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PTPLU (Version 2.0)
Analysis of concentration as a function of stability and wind speed
(California Air Resources Board Modeling Section version)

Southwestern Portland Cement, Victorville

## Source Conditions

emission rate = 1.000 g/sec
physical stack height = 28.65 m
stack gas temperature = 482.59 deg. K
stack gas velocity = 6.96 m/sec
stack diameter = 3.96 m
volume flow rate = 85.721 m^3/sec
buoyancy flux = 105.035 m^4/sec^3

## Meteorological Conditions

ambient temperature = 293.15 deg. K
anemometer height = 10.00 m
mixing height = 1500.00 m
Wind profile exponents: A: 0.07, B: 0.07, C: 0.10, D: 0.15, E: 0.35, F: 0.55

## Receptor data

receptor elevation above ground level = 0.00 m

## Options used

stack downwash
buoyancy induced dispersion
rural dispersion coefficients (Pasquill-Gifford)

## Results - using extrapolated winds

| Stability | Wind Speed (m/sec) | Maximum Concentration (ug/m^3) | Distance of Max. (km) | Effective Height (m) |
|---|---|---|---|---|
| A | 0.54 | 1.02845E+00 | 1.666 | 1202.6(2) |
| A | 0.86 | 9.14737E-01 | 1.208 | 762.4(2) |
| A | 1.08 | 1.03460E+00 | 1.062 | 615.6(2) |
| A | 1.61 | 1.28021E+00 | 0.879 | 420.0(2) |
| A | 2.15 | 1.45562E+00 | 0.764 | 322.1(2) |
| A | 2.69 | 1.59954E+00 | 0.697 | 263.4(2) |
| A | 3.23 | 1.70621E+00 | 0.648 | 224.3(2) |
| B | 0.54 | 4.34669E-01 | 7.587 | 1202.6(2) |
| B | 0.86 | 4.49207E-01 | 4.209 | 762.4(2) |
| B | 1.08 | 5.30525E-01 | 3.443 | 615.6(2) |
| B | 1.61 | 7.11053E-01 | 2.426 | 420.0(2) |
| B | 2.15 | 8.65166E-01 | 1.906 | 322.1(2) |
| B | 2.69 | 9.98752E-01 | 1.589 | 263.4(2) |
| B | 3.23 | 1.11559E+00 | 1.374 | 224.3(2) |
| B | 4.31 | 1.30918E+00 | 1.103 | 175.4 |
| B | 5.38 | 1.49198E+00 | 0.926 | 144.4 |
| C | 2.22 | 6.76296E-01 | 3.678 | 313.0(2) |
| C | 2.78 | 8.03905E-01 | 2.968 | 256.1(2) |

| | | | | | |
|---|---|---|---|---|---|
| C | 3.33 | 9.19209E-01 | 2.502 | 218.2(2) | |
| C | 4.44 | 1.11795E+00 | 1.930 | 170.8 | |
| C | 5.55 | 1.31823E+00 | 1.565 | 140.4 | |
| C | 7.78 | 1.67209E+00 | 1.148 | 105.1 | |
| C | 11.11 | 2.08110E+00 | 0.844 | 78.6 | |
| C | 13.33 | 2.28728E+00 | 0.738 | 68.3 | |
| C | 16.66 | 2.51869E+00 | 0.626 | 58.0 | <-- MAX |
| D | 0.59 | 9.99900E+15 | 999999.000(3) | 1107.8(2) | |
| D | 0.94 | 7.14918E-02 | 54.634 | 703.1(2) | |
| D | 1.17 | 1.00986E-01 | 36.277 | 568.2(2) | |
| D | 1.76 | 1.79115E-01 | 20.369 | 388.4(2) | |
| D | 2.34 | 2.61013E-01 | 13.018 | 298.4(2) | |
| D | 2.93 | 3.44421E-01 | 9.834 | 244.5(2) | |
| D | 3.51 | 4.22310E-01 | 7.661 | 208.5(2) | |
| D | 4.68 | 5.71933E-01 | 5.243 | 163.4 | |
| D | 5.86 | 7.42594E-01 | 3.827 | 134.1 | |
| D | 8.20 | 1.06144E+00 | 2.555 | 100.6 | |
| D | 11.71 | 1.46531E+00 | 1.672 | 75.4 | |
| D | 14.05 | 1.69446E+00 | 1.364 | 65.7 | |
| D | 17.57 | 1.98325E+00 | 1.078 | 55.9 | |
| D | 23.42 | 2.27856E+00 | 0.930 | 46.1 | |
| E | 2.89 | 1.07607E+00 | 7.189 | 127.1 | |
| E | 3.61 | 1.00304E+00 | 6.487 | 120.0 | |
| E | 4.34 | 9.45161E-01 | 5.974 | 114.7 | |
| E | 5.78 | 9.17078E-01 | 4.971 | 104.4 | |
| E | 7.23 | 9.02197E-01 | 4.287 | 96.9 | |
| F | 3.57 | 8.10225E-01 | 12.887 | 104.8 | |
| F | 4.46 | 7.60758E-01 | 11.506 | 99.4 | |
| F | 5.35 | 7.64151E-01 | 9.961 | 93.6 | |
| F | 7.14 | 7.77964E-01 | 7.861 | 84.9 | |
| F | 8.92 | 7.78319E-01 | 7.000 | 79.1 | |

Cautionary Notes
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(2) The plume is of sufficient height that extreme caution should be used in interpreting this computation as this stability type may not exist to this height. Also wind speed variations with height may exert a dominating influence

(3) No computation was attempted for this height as the point of maximum concentration is greater than 100 km or less than 1 meter from the source

CALIFORNIA AIR RESOURCES BOARD AND DEPARTMENT OF HEALTH SERVICES
HEALTH RISK ASSESSMENT MODEL
NOVEMBER 1990 VERSION

RUN BY: G.Allen
COMPANY NAME: ARB
PROJECT NAME: Southwestern/March'90/Coal
DATE OF RUN: 09-25-1991
POLLUTANT DATA FILE VERSION: 11/09/90

REPORT TYPE: CHRONIC EXPOSURE AND INDIVIDUAL CANCER RISK
***************************************************************************
EMISSION FILE NAME: c:SW-March.E

| POLLUTANT | EMISSION RATE (G/SEC) |
|---|---|
| ARSENIC, INORGANIC | 3.9D-05 |
| BENZENE | 8.3D-02 |
| BERYLLIUM | 4.6D-06 |
| CADMIUM | 3.7D-04 |
| CHROMIUM 6+ | 4.6D-06 |
| COPPER | 5.2D-04 |
| FORMALDEHYDE | 5.9D-03 |
| LEAD | 1.0D-03 |
| MANGANESE | 5.3D-04 |
| MERCURY | 1.9D-04 |
| NICKEL | 8.0D-05 |
| PAH as BENZO(A)PYRENE | 1.2D-05 |
| PHOSPHORUS (WHITE) | 9.2D-03 |
| SELENIUM COMPOUNDS | 3.1D-05 |
| TCDD EQUIVALENT | 7.5D-08 |
| ZINC | 7.1D-03 |

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DISPERSION FACTOR CHI OVER Q USED: .251869
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ROUTE FILE NAME: c:MULTI.I

1. DEPOSITION VELOCITY IS - .02
2. MOTHER'S MILK INCLUDED - YES
3. THE FRACTION OF HOMEGROWN PRODUCE IS - .25

GENERAL ANIMAL EXPOSURE FACTORS

4. FRACTION OF ANIMAL'S DIET FROM GRAZING IS - 0
5. FRACTION OF ANIMAL'S DIET FROM IMPACTED FEED IS - 0
6. FRACTION OF ANIMAL'S WATER IMPACT BY DEPOSITION IS - 0

ANIMAL X/Q AND WATER FACTORS

7.

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

8. FRACTION OF MEAT IN DIET PRODUCED AT HOME IS - 0

9. THE FOLLOWING FRACTIONS OF EACH TYPE ARE PRODUCED

| BEEF | PORK | LAMB | CHICKEN |
|---|---|---|---|
| 0 | 0 | 0 | 0 |

10. FRACTION OF EGGS PRODUCED ON SITE IS - 0

DAIRY PRODUCTS

11. FRACTION OF MILK PRODUCED ON SITE IS - 0
12. GOAT MILK FRACTION IS - 0

DRINKING WATER WILL BE EVALUATED USING THE FOLLOWING FACTORS

13. FRACTION OF IMPACTED DRINKING WATER - 0

14.

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

FISH WILL BE EVALUATED WITH THE FOLLOWING FACTORS

15. FISH FROM IMPACTED WATER - 0

16.

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

17. RUNOFF WILL BE EVALUATED USING THE FOLLOWING FACTORS

FACILITY HOURS OF OPERATIONS - 0
ANNUAL RAINFALL - 0
WATERSHED AREA IMPACTED - 0
WATERSHED RUNOFF COEFFICIENT - 0
WASH COEFFICIENT - 0

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RESULTS
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CHRONIC EXPOSURE BY POLLUTANT AND ROUTE

| POLLUTANT | INHALATION (UG/M3) | INGESTION (MG/KG-DAY) |
|---|---|---|
| ARSENIC, INORGANIC | 9.8E-06 | 5.7E-08 |
| BENZENE | 2.1E-02 | 0.0E+00 |
| BERYLLIUM | 1.2E-06 | 6.3E-09 |
| CADMIUM | 9.2E-05 | 1.2E-06 |
| CHROMIUM 6+ | 1.2E-06 | 0.0E+00 |
| COPPER | 1.3E-04 | 6.8E-07 |
| FORMALDEHYDE | 1.5E-03 | 0.0E+00 |
| LEAD | 2.6E-04 | 1.5E-06 |
| MANGANESE | 1.3E-04 | 7.0E-07 |
| MERCURY | 4.7E-05 | 7.9E-07 |
| NICKEL | 2.0E-05 | 2.3E-07 |
| PAH as BENZO(A)PYREN | 2.9E-06 | 5.6E-09 |
| PHOSPHORUS (WHITE) | 2.3E-03 | 0.0E+00 |
| SELENIUM COMPOUNDS | 7.7E-06 | 0.0E+00 |
| TCDD EQUIVALENT | 1.9E-08 | 6.4E-11 |

| | | |
|---|---|---|
| ZINC | 1.8E-03 | 9.3E-06 |

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INDIVIDUAL CANCER RISK BY POLLUTANT AND ROUTE

| POLLUTANT | AIR | SOIL | SKIN | GARDEN | MMILK | OTHER |
|---|---|---|---|---|---|---|
| ARSENIC, IN | 2.0D-08 | 5.1D-08 | 7.9D-10 | 2.5D-08 | 0.0D+00 | 0.0D+00 |
| BENZENE | 7.0D-07 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| BERYLLIUM | 1.8D-09 | 3.0D-08 | 4.7D-10 | 1.1D-08 | 0.0D+00 | 0.0D+00 |
| CADMIUM | 2.4D-07 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| CHROMIUM 6+ | 1.0D-07 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| FORMALDEHYD | 1.2D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| NICKEL | 3.0D-09 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| PAH as BENZ | 3.1D-09 | 4.0D-09 | 1.9D-09 | 3.5D-08 | 0.0D+00 | 0.0D+00 |
| TCDD EQUIVA | 4.5D-07 | 1.1D-06 | 7.9D-07 | 1.1D-06 | 1.5D-06 | 0.0D+00 |
| Route Total | 1.5E-06 | 1.2E-06 | 7.9E-07 | 1.2E-06 | 1.5E-06 | 0.0E+00 |

Total Risk 6.2E-06

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FOR CALIFORNIA AIR TOXICS HOT SPOTS ACT PURPOSES ONLY
ADDITIONAL SCREENING RISK BY POLLUTANT AND ROUTE

| POLLUTANT | AIR | SOIL | SKIN | GARDEN | MMILK | OTHER |
|---|---|---|---|---|---|---|
| LEAD | 1.3D-09 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| MERCURY | 2.4D-10 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| SELENIUM CO | 6.8D-10 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| Route Total | 2.2E-09 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

Screening Total 2.2E-09

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END OF REPORT

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CALIFORNIA AIR RESOURCES BOARD AND DEPARTMENT OF HEALTH SERVICES
HEALTH RISK ASSESSMENT MODEL
NOVEMBER 1990 VERSION

RUN BY: G.Allen
COMPANY NAME: ARB
PROJECT NAME: Southwestern/April'91/Coal&TDF
DATE OF RUN: 09-25-1991
POLLUTANT DATA FILE VERSION: 11/09/90

REPORT TYPE: CHRONIC EXPOSURE AND INDIVIDUAL CANCER RISK
*****************************************************************************
EMISSION FILE NAME: c:SW-April.E

| POLLUTANT | EMISSION RATE (G/SEC) |
|---|---|
| ARSENIC, INORGANIC | 1.5D-05 |
| BENZENE | 1.9D-02 |
| BERYLLIUM | 6.3D-06 |
| CADMIUM | 1.9D-05 |
| CHROMIUM 6+ | 3.0D-06 |
| COPPER | 8.2D-05 |
| FORMALDEHYDE | 1.2D-03 |
| LEAD | 8.2D-05 |
| MANGANESE | 4.6D-04 |
| MERCURY | 2.4D-03 |
| NICKEL | 2.7D-05 |
| PAH as BENZO(A)PYRENE | 8.5D-06 |
| PHOSPHORUS (WHITE) | 3.5D-03 |
| SELENIUM COMPOUNDS | 1.5D-05 |
| TCDD EQUIVALENT | 1.2D-07 |
| ZINC | 2.4D-03 |

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DISPERSION FACTOR CHI OVER Q USED: .251869
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ROUTE FILE NAME: c:MULTI.I

1. DEPOSITION VELOCITY IS - .02
2. MOTHER'S MILK INCLUDED - YES
3. THE FRACTION OF HOMEGROWN PRODUCE IS - .25

GENERAL ANIMAL EXPOSURE FACTORS

4. FRACTION OF ANIMAL'S DIET FROM GRAZING IS - 0
5. FRACTION OF ANIMAL'S DIET FROM IMPACTED FEED IS - 0
6. FRACTION OF ANIMAL'S WATER IMPACT BY DEPOSITION IS - 0

ANIMAL X/Q AND WATER FACTORS

7.

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

8. FRACTION OF MEAT IN DIET PRODUCED AT HOME IS - 0

9. THE FOLLOWING FRACTIONS OF EACH TYPE ARE PRODUCED

| BEEF | PORK | LAMB | CHICKEN |
|---|---|---|---|
| 0 | 0 | 0 | 0 |

10. FRACTION OF EGGS PRODUCED ON SITE IS - 0

DAIRY PRODUCTS

11. FRACTION OF MILK PRODUCED ON SITE IS - 0
12. GOAT MILK FRACTION IS - 0

DRINKING WATER WILL BE EVALUATED USING THE FOLLOWING FACTORS

13. FRACTION OF IMPACTED DRINKING WATER - 0

14.

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

FISH WILL BE EVALUATED WITH THE FOLLOWING FACTORS

15. FISH FROM IMPACTED WATER - 0

16.

| X/Q | SURFACE AREA | VOLUME | VOLUME CHANGES | RUNOFF CONTRIBUTION |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |

17. RUNOFF WILL BE EVALUATED USING THE FOLLOWING FACTORS

FACILITY HOURS OF OPERATIONS - 0
ANNUAL RAINFALL - 0
WATERSHED AREA IMPACTED - 0
WATERSHED RUNOFF COEFFICIENT - 0
WASH COEFFICIENT - 0

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RESULTS
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CHRONIC EXPOSURE BY POLLUTANT AND ROUTE

| POLLUTANT | INHALATION (UG/M3) | INGESTION (MG/KG-DAY) |
|---|---|---|
| ARSENIC, INORGANIC | 3.8E-06 | 2.2E-08 |
| BENZENE | 4.8E-03 | 0.0E+00 |
| BERYLLIUM | 1.6E-06 | 8.5E-09 |
| CADMIUM | 4.8E-06 | 6.1E-08 |
| CHROMIUM 6+ | 7.7E-07 | 0.0E+00 |
| COPPER | 2.1E-05 | 1.1E-07 |
| FORMALDEHYDE | 3.0E-04 | 0.0E+00 |
| LEAD | 2.1E-05 | 1.2E-07 |
| MANGANESE | 1.2E-04 | 6.1E-07 |
| MERCURY | 6.1E-04 | 1.0E-05 |
| NICKEL | 6.7E-06 | 7.7E-08 |
| PAH as BENZO(A)PYREN | 2.1E-06 | 4.1E-09 |
| PHOSPHORUS (WHITE) | 8.9E-04 | 0.0E+00 |
| SELENIUM COMPOUNDS | 3.8E-06 | 0.0E+00 |
| TCDD EQUIVALENT | 3.1E-08 | 1.1E-10 |

| | | |
|---|---|---|
| ZINC | 6.1E-04 | 3.2E-06 |

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INDIVIDUAL CANCER RISK BY POLLUTANT AND ROUTE

| POLLUTANT | AIR | SOIL | SKIN | GARDEN | MMILK | OTHER |
|---|---|---|---|---|---|---|
| ARSENIC, IN | 7.9D-09 | 2.0D-08 | 3.1D-10 | 9.5D-09 | 0.0D+00 | 0.0D+00 |
| BENZENE | 1.6D-07 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| BERYLLIUM | 2.4D-09 | 4.1D-08 | 6.3D-10 | 1.5D-08 | 0.0D+00 | 0.0D+00 |
| CADMIUM | 1.3D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| CHROMIUM 6+ | 6.7D-08 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| FORMALDEHYD | 2.4D-09 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| NICKEL | 1.0D-09 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| PAH as BENZ | 2.3D-09 | 3.0D-09 | 1.4D-09 | 2.6D-08 | 0.0D+00 | 0.0D+00 |
| TCDD EQUIVA | 7.5D-07 | 1.8D-06 | 1.3D-06 | 1.9D-06 | 2.5D-06 | 0.0D+00 |
| Route Total | 1.0E-06 | 1.9E-06 | 1.3E-06 | 1.9E-06 | 2.5E-06 | 0.0E+00 |

Total Risk 8.6E-06

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FOR CALIFORNIA AIR TOXICS HOT SPOTS ACT PURPOSES ONLY
ADDITIONAL SCREENING RISK BY POLLUTANT AND ROUTE

| POLLUTANT | AIR | SOIL | SKIN | GARDEN | MMILK | OTHER |
|---|---|---|---|---|---|---|
| LEAD | 1.0D-10 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| MERCURY | 3.1D-09 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| SELENIUM CO | 3.3D-10 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 | 0.0D+00 |
| Route Total | 3.5E-09 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

Screening Total 3.5E-09

*****************************************************************************

END OF REPORT

*****************************************************************************

APPENDIX D

## ROSEBURG LUMBER COMPANY, ANDERSON

***AIR POLLUTION CONTROL EQUIPMENT:*** Wet Scrubber

***PROCESS DESCRIPTION:*** This test was conducted on Boiler #1 which is a Gharrett & Shafer water tube boiler on a dutch oven furnace. The boiler is equipped with a wet scrubber, multiclone collector and cinder reinjection. Continuous monitoring equipment includes steam flow and opacity recording devices.

***PERFORMANCE TEST INFORMATION:*** [1] Background - The performance test was conducted from October 6-7, 1982 on the #1 boiler at the Anderson site and included firing pine/fur with tire derived fuel (TDF). The purpose of the test was to evaluate the impacts of supplementing hogged wood waste fuel with shredded rubber tires in various percentages of fuel input. Results - Runs #1-4 were performed when combusting wood fuel only. Average fuel firing rates ranged from about 5.6 to 9.4 tons/hr. Test Methods employed and emission averages measured are outlined below.

**Test Methods Employed**

EPA Sampling Methods 1, 2, 3, 5, 6, and 7

**Summary of Test Results** [2]

| Rubber (%) | Steam Production (lbs/hr) | PM (lbs/hr) | SO2 (lbs/hr) | NOx (lbs/hr) | ZnO (lbs/hr) | PbO (lbs/hr) |
|---|---|---|---|---|---|---|
| 0 | 39,000 | 16.1 | <1.0 | 13.9 | 0.2 | 0.01 |
| 3 | 41,000 | 30.8 | 2.4 | NO DATA | 10.6 | 0.03 |
| 5 | 47,000 | 32.4 | 2.7 | 17.8 | 10.6 | 0.02 |
| 7 | 45,000 | 27.4 | 4.0 | 19.4 | 8.3 | 0.01 |
| 10 | 45,000 | 27.4 | 5.3 | 20.1 | 13.0 | 0.02 |

[1] BWR Associates Environmental Consultants. Emission Test Report: Evaluation of Rubber Supplement to Hogged Wood Waste Fuel. Anderson, CA. Conducted October 6-7, 1982.

[2] Values are averages of available data for each fuel mix.

## APPENDIX E

## TABLE E-1

## COMPARISON OF EMISSIONS FROM CHAMPION INTERNATIONAL BUCKSPORT, MAINE BOILER NO. 8 TESTS - SEPTEMBER TO OCTOBER, 1989

| Fuels Used[1,2] | O,B,C,S No TDF | O,B,C,S, 6.3% TDF | O,B,C,S, 10.3% TDF | O,B,C,S, 14.5% TDF | Percent Change[3] |
|---|---|---|---|---|---|
| Steam Load lb/hr | 475,000 | 482,000 | 481,200 | 480,700 | +1.2 |
| Total Heat Input MMBTU/hr | 667.0 | 674.5 | 689.0 | 688.5 | +3.2 |
| TDF | | | | | |
| ton/hr | 0 | 1.5 | 2.5 | 3.5 | - |
| MMBTU/hr | 0 | 42.8 | 71.3 | 99.8 | - |
| % TDF by heat input | 0 | 6.3 | 10.3 | 14.5 | - |
| NOx lb/MMBTU | 0.274 | 0.273 | 0.280 | 0.273 | <1 |
| $SO_2$ lb/MMBTU | 0.508 | 0.466 | 0.483 | 0.510 | <1 |
| Particulate Matter lb/MMBTU | 0.053 | 0.054 | 0.047 | 0.056 | +6 |
| Total Hydrocarbons lb/MMBTUx$10^{-3}$ | 1.17 | 1.18 | 1.18 | 1.18 | <1 |
| Beryllium lb/MMBTUx$10^{-6}$ | 1.06 | 1.11 | 0.87 | 0.73 | -31 |
| Cadmium lb/MMBTUx$10^{-6}$ | 0.60 | 1.49 | 0.84 | 0.78 | +30 |
| Chromium lb/MMBTUx$10^{-6}$ | 12.1 | 14.7 | 6.67 | 6.36 | -47 |
| Lead lb/MMBTUx$10^{-6}$ | <10 | <10 | <10 | <10 | - |
| Zinc lb/MMBTUx$10^{-6}$ | 260 | 981 | 1380 | 2560 | +885 |

Notes:

1. Fuel Codes: O=Fuel Oil, B=Biomass, C=Coal, S=Sludge, TDF=1½ inch dewired Tire Derived Fuel.
2. TDF fuel is expressed as percent of total heat input.
3. Percent change is for comparison between test using no TDF and test using 14.5% TDF.

## TABLE E-2

## COMPARISON OF EMISSIONS FROM PORT TOWNSEND PAPER COMPANY PORT TOWNSEND, WASHINGTON POWER BOILER NO. 10

| Test Date | 3/5/86 | 2/25/86 | |
|---|---|---|---|
| Fuels Used | Wood/Oil | Wood/Tires | Percent Change |
| Steam Output (lb/hr) | 141,000 | 148,000 | +5.0 |
| Total Heat Input (MMBTU/hr) | 239 | 260 | +8.8 |
| Wood Fuel (MMBTU/hr) | 222 | 248 | +12 |
| Oil Fuel | | | |
| lb/hr | 900 | 0 | - |
| MMBTU/hr | 17 | 0 | - |
| % Total Heat Input | 7.1 | 0 | - |
| Shredded Tire Fuel | | | |
| lb/hr | 0 | 1050 | - |
| MMBTU/hr | 0 | 12 | - |
| % Total Heat Input | 0 | 4.6 | - |
| Particulate Matter | | | |
| lb/hr | 46 | 63 | |
| lb/MMBTU | 0.23 | 0.29 | +26 |
| Barium | | | |
| lb/hr | 5.58 | 2.85 | |
| lb/MMBTU | 0.023 | 0.011 | -52 |
| Cadmium | | | |
| lb/hr | 0.523 | 0.356 | |
| lb/MMBTU | 0.0022 | 0.0014 | -36 |
| Chromium | | | |
| lb/hr | 0.667 | 0.394 | |
| lb/MMBTU | 0.0028 | 0.0015 | -46 |
| Lead | | | |
| lb/hr | 7.37 | 1.49 | |
| lb/MMBTU | 0.031 | 0.0057 | -82 |
| Vanadium | | | |
| lb/hr | 11.0 | 0.098 | |
| lb/MMBTU | 0.046 | 0.00038 | -99 |
| Zinc | | | |
| lb/hr | 180.5 | 2825 | |
| lb/MMBTU | 0.755 | 10.87 | +1340 |
| Anthracene | | | |
| lb/hr | 0.121 | 0.303 | |
| lb/MMBTU | 0.00051 | 0.0012 | +135 |
| Phenanthrene | | | |
| lb/hr | 5.12 | 8.72 | |
| lb/MMBTU | 0.021 | 0.034 | +62 |
| Fluoranthene | | | |
| lb/hr | 5.61 | 2.66 | |
| lb/MMBTU | 0.023 | 0.010 | -57 |
| Pyrene | | | |
| lb/hr | 3.05 | 4.30 | |
| lb/MMBTU | 0.013 | 0.017 | +31 |

## APPENDIX F

### TABLE F-1

### EMISSIONS FROM CALAVERAS CEMENT COMPANY KILN NUMBER 1, REDDING, CALIFORNIA

| | |
|---|---|
| Continuous Emissions Monitoring - Period | 1/91 - 8/91 |
| Average TDF usage during period (percent of total heat input) | 22 |
| NOx (as $NO_2$) | |
| dppmv | 178 |
| lb/hr | (131) |
| lb/ton clinker | (1.6) |
| lb/MMBTU | (0.49) |
| Permit Limit | 350 dppmv (2 hr. ave.) |
| CO | |
| dppmv | 1431 |
| lb/hr | (562) |
| lb/ton clinker | (6.8) |
| lb/MMBTU | (2.1) |
| Permit Limit | 2500 dppmv (2 hr. ave.) |
| Opacity | |
| Percent | 1.5 |
| Permit Limit | 20 (3 min. ave.) |
| THC (as methane) | |
| dppmv | 22 |
| lb/hr | (5.66) |
| lb/ton clinker | (0.07) |
| lb/MMBTU | (0.02) |
| Permit Limit | None |

Notes: Mass emission rates (in parentheses) are calculated from continuous emissions monitoring data and average stack flow conditions. They are included to provide a rough estimate only.